CANADIAN JOURNAL OF AGRICULTURAL SCIENCE

(*formerly* Scientific Agriculture)

VOLUME 34 NOVEMBER-DECEMBER, 1954 No. 6

ZINC DEFICIENCY IN FRUIT TREES IN THE OKANAGAN VALLEY IN BRITISH COLUMBIA[1]

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[Received for publication May 19, 1954]

ABSTRACT

In the Okanagan Valley of British Columbia a zinc deficiency was found to occur on apple, pear, cherry, peach, apricot, and prune fruit trees. The severity of the deficiency varied considerably from orchard to orchard. In some, the severity was very marked and death of some tissues had occurred. In others, the deficiency was moderate and some or all of the characteristic symptoms usually associated with it, viz. small leaves, leaf rosettes, and an interveinal chlorotic pattern, were present. When the deficiency was slight, one or more of these symptoms were recognizable only at certain times of the growing season. With the exception of cherry, affected trees responded well to zinc sulphate sprays when applied during the late dormant period. Summer sprays of zinc oxide and the injection of various zinc compounds into the trunks of affected trees were less effective. A good correlation between the zinc content of tissues and the presence of deficiency symptoms was established.

In a note published in 1951 (13) reference was made to the presence of zinc deficiency in apple trees growing in the Okanagan Valley in British Columbia. At that time it had not been recognized in any other types of fruit trees. However, recent observations have shown that zinc deficiency is also present on pear, cherry, prune, apricot, and peach trees. It is the purpose of this paper to report these deficiencies, to describe the symptoms associated with them, to tabulate the amount of zinc present in diseased and healthy tissue, and to outline the methods of control now in use.

The presence of zinc deficiencies in fruit trees has been reported by workers in several countries: Australia (8, 10); England (6); New Zealand (4, 5, 12); the United States (7, 11), and in several parts of Western Europe (9). In Canada, zinc deficiency has been reported as occurring only in the province of British Columbia (13).

In British Columbia the deficiency is found in widely scattered areas in the southern interior valleys. These areas depend upon irrigation water to supplement rainfall and, generally speaking, an intensive type of agriculture is practised. Deficiencies are found on soils that may be classified as heavy or light and with pH values between 5.5 and 7.5. In some orchards the deficiency is severe and the growers suffer heavy economic losses. However, in most affected lots only a few trees are exhibiting symptoms and losses are not great.

[1] Contribution No. 254 from the Chemistry Division, Science Service.

In apple, zinc deficiency symptoms are characterized by well developed "rosettes", "little leaf", and, when the deficiency is extremely severe, "die back", as already described (13). Additional symptoms have been noted, and these are detailed below. Bud development is greatly retarded, but if the deficiency is not marked, leaves and twigs on affected trees may develop and grow at such a rate that at the end of the growing season they appear normal and are indistinguishable from those present on normal healthy trees. If the deficiency is marked an affected tree may be poorly developed (Figure 1), there may be few blossoms, leaves will be slow in developing (Figure 2), and at harvest time the fruit may be diminutive (Figure 3) but normal in shape and colour. These symptoms are generally associated with an interveinal chlorotic pattern on the leaves and in many fruit trees, where the deficiency is only slight to moderate, this interveinal pattern may be the only symptom present. On 2- to 4-year-old trees only this latter symptom has been observed. Zinc deficiency has been found frequently on Delicious and Winesap, and only occasionally on McIntosh and Newtown. It has not been observed on other varieties.

In pear, zinc deficiency (Figure 4) may cause a marked delay in the opening of the buds, a modified type of rosette, and small, elongated and quite uniformly yellow leaves. There may be a "little leaf" condition, but it is not as conspicuous as that found in apple. No die back that could be attributed to zinc deficiency has been noted. The distribution of these symptoms on a tree is quite irregular (Figure 5) in that the leaves on one branch may show marked deficiency symptoms whereas leaves on adjacent branches may be normal. As the season advances, the severity of the symptoms decreases. The symptoms observed in the Okanagan Valley are very similar to those reported by Bollard (4) as occurring in New Zealand.

The recognition of zinc deficiency in peach and apricot was delayed because of the similarity between the symptoms associated with a deficiency of this element and with those caused by a manganese deficiency. Both are characterized by an interveinal chlorosis, and, particularly when the deficiencies are slight, the yellow patterns are extremely similar. This similarity has been noted by Bollard (5). When the deficiencies are marked, or when a complete tree is available for examination, differentiation between the two may readily be made. In peach and apricot, zinc deficiency symptoms can most readily be found by examining the terminal leaves of the current season's growth (Figure 6), whereas when leaves are affected with a manganese deficiency, the symptoms appear first in the older leaves (14). There is usually no difficulty in distinguishing between iron and zinc deficiencies even though they both cause the terminal leaves to become yellow. With the former, the green colour fades uniformly, leaving the veins standing out in a net-like pattern (Figure 7), whereas with the latter, there is a marked interveinal chlorotic pattern with more chlorophyll in the tissue adjacent to the veins than in the tissue midway between the main veins (Figure 8). When zinc deficiency is very severe, the entire leaf may become yellow and it may then be more difficult to distinguish between them, but if the affected trees as a whole are compared, differentiation is readily made. With zinc deficiency the leaves may be small, somewhat elongated in shape, and chlorotoic. The degree of

FIGURE 1. A Winesap apple tree severely affected with zinc deficiency. The development of the tree is poor, there are few blossoms, and the leaves are slow in growing.

FIGURE 2. The same tree as in Figure 1, but the picture was taken two months later. The foliage on parts of the tree has developed but on others the leaves are extremely small ("little leaf") and there is little or no terminal growth.

FIGURE 3. With the leaf surface of a tree greatly reduced by "little leaf" what few fruits there are may be diminutive, but normal in shape and colour.

chlorosis varies with severity of the deficiency (Figure 9). In peach, when the deficiency is severe, defoliation on some of the affected branches may commence during the latter part of August, and within 4 to 6 weeks only a few small, distorted, and yellow leaves may remain at the tip of a branch (Figure 10). Sometimes the lateral branches may not develop (Figure 11). Moderate zinc deficiency in stone fruits does not appear until about the time the crop is being harvested.

Symptoms of zinc deficiency, including rosette, little leaf, and chlorosis, have been observed in cherry when the deficiency was severe. The affected branches were stunted, some buds had failed to develop, and the leaves were either entirely chlorotic or had a marked interveinal pattern. In less severely affected trees, only the terminal leaves were affected and they were somewhat elongated and yellow-green in colour.

CONTROL EXPERIMENTS AND RESULTS

In an attempt to lessen, and particularly to prevent, the occurrence of zinc deficiencies in fruit trees several zinc-containing compounds and various methods of using them were tested. In the Penticton district, in two orchards containing Newtown, McIntosh, Winesap, and Delicious apple trees, dormant sprays of zinc sulphate, 20 lb. $ZnSO_4 . 7H_2O$ (22 per cent zinc), or $12\frac{1}{2}$ lb. $ZnSO_4 . H_2O$ (36 per cent zinc), in 100 Imperial gal. of water approximately 400 gal. per acre, were applied during the late dormant period, i.e. just before the buds broke and the green tip appeared. In one of these orchards, the recovery was remarkable, in that no zinc deficiency symptoms appeared during the summer following the spray. In the other, recovery was not nearly so pronounced and sprays in three successive years were required to effect a complete cure. In other trials, using a concentrate spray machine, 40 lb. of zinc sulphate (22 per cent zinc) in 100 gal. of water were applied per acre and good response was recorded. Results of analyses of leaves from some of the treated trees in the above experiment and also from some trees treated with dormant zinc sprays are presented in Table 1. This table also contains representative results of analyses of healthy leaves collected from trees growing in various orchards.

Dormant sprays were also applied to peach, apricot, and cherry trees that had been affected with zinc deficiency. With peach and apricot, the results of these sprays were satisfactory in that the deficiency condition was cured. On cherry, dormant sprays have not been as satisfactory as on other fruits tested. Some results of analyses of affected and healthy leaves from stone fruit trees are tabulated in Table 1.

The use of zinc sulphate, one pound in 100 gallons, as a summer spray was investigated by applying it to apple, pear, peach, cherry, apricot, and prune trees on May 18. Only on apricot was there any injury. Using the same material at the rate of 2 pounds in 100 gallons a small amount of injury was noted on apple and pear, and greater amounts on the stone fruits. It was deemed unsound, because of the injury that might be caused by the use of this material, to recommend it as a summer spray, and no further trials were made.

Two pear trees, which in the spring of 1951 showed moderate zinc deficiency, were sprayed with a fungicide, Zinc Coposil (a zinc copper

TABLE 1.—THE ZINC CONTENT OF FRUIT TREE TISSUES

(p.p.m. on an air dry weight basis)

Material	Description	Zinc content		
		Low	High	Average
Apple leaves—*McIntosh*	Severe little leaf	3.4	7.5	5.7 (4)*
	Slight little leaf	7.0	11.6	9.3 (2)
	Healthy	9.6	15.6	15.1 (5)
	Healthy, sprayed**	25.0	30.0	27.5 (2)
Apple leaves—*Newtown*	Little leaf	7.4		
	Healthy	14.4		
	Healthy, sprayed**	15.2		
Apple leaves—*Delicious*	Little leaf	4.0	11.4	8.3 (7)
	Healthy	10.6	26.0	21.0 (3)
	Healthy, sprayed**	8.1	30.0	16.1 (5)
Apple leaves—*Winesap*	Severe little leaf	2.0		
	Moderate little leaf	7.1	12.8	10.7 (4)
	Healthy	12.6	29.4	19.6 (4)
Apple twigs—*McIntosh*	Little leaf	9.6	13.0	11.3 (2)
	Healthy	12.2	24.6	18.9 (3)
Apple twigs—*Delicious*	Little leaf	2.0	9.1	5.5 (4)
	Healthy	11.6	35.0	22.8 (3)
Apple twigs—*Winesap*	Die back	1.4	7.0	3.2 (5)
Peach leaves—*Vedette*	Severe chlorosis	5.3	8.0	6.6 (2)
	Moderate chlorosis	10.7	10.8	10.7 (2)
	Slight chlorosis	7.9	13.4	9.7 (3)
	Healthy	9.9	30.4	18.1 (14)
Apricot leaves—*Moorpark*	Severe chlorosis	5.3		
	Moderate chlorosis	6.4	11.1	8.9 (6)
	Healthy	12.5	23.4	17.7 (4)
Cherry leaves—*Bing*	Chlorosis	6.2	15.1	10.0 (9)
	Healthy	13.1	23.9	17.9 (4)

* Number of samples.
* Late dormant spray of zinc sulphate.

ammonium silicate containing 19 per cent zinc), 1 pound in 100 gallons, as a blossom spray on April 29, May 2, May 5, and May 8. By June 3 a response was noticed, but by the end of the season it was impossible to distinguish between treated and untreated trees.

The possible use of zinc oxide as a material suitable for a foliage or summer spray was investigated. In one series of tests this compound, 1 pound in 100 gallons, was sprayed on to severely affected zinc deficient apple trees eight times at 7- to 10-day intervals commencing at petal fall. After the first two sprays a considerable improvement of the treated trees over the untreated ones was clearly discernible. The leaves were greener, the tips of small leaves were not necrotic, and the terminal growth was greater. Until the end of July there was a visible deposit of zinc oxide on both the leaves and fruit and there was no damage to either. The grower

FIGURE 4. Zinc deficiency in pear. Many buds are slow in opening; affected leaves may be somewhat elongated and chlorotic.

FIGURE 5. On affected pear trees the distribution of zinc deficiency symptoms may be quite irregular. Leaves on one branch show marked deficiency symptoms whereas those on adjacent branches appear normal.

FIGURE 6. Zinc deficiency in peach. Note that the interveinal chlorotic pattern, so characteristic of zinc deficiency, is present in the terminal leaves.

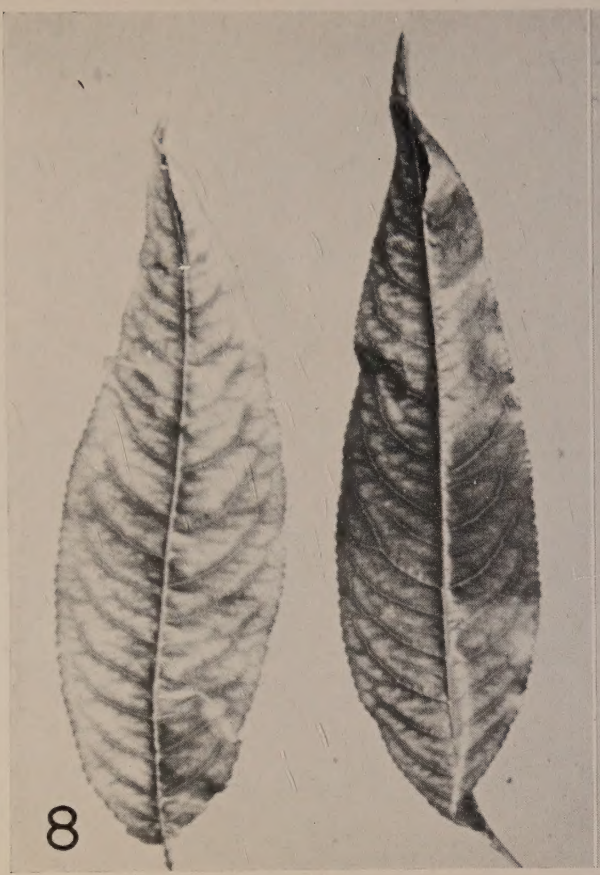

FIGURE 8. Zinc deficiency in peach. Note the presence of green tissue near the veins and the overall mottled appearance.

FIGURE 7. Iron deficiency in peach. The uniform yellowing extends completely up to the veins and the latter are left standing out in a pronounced pattern.

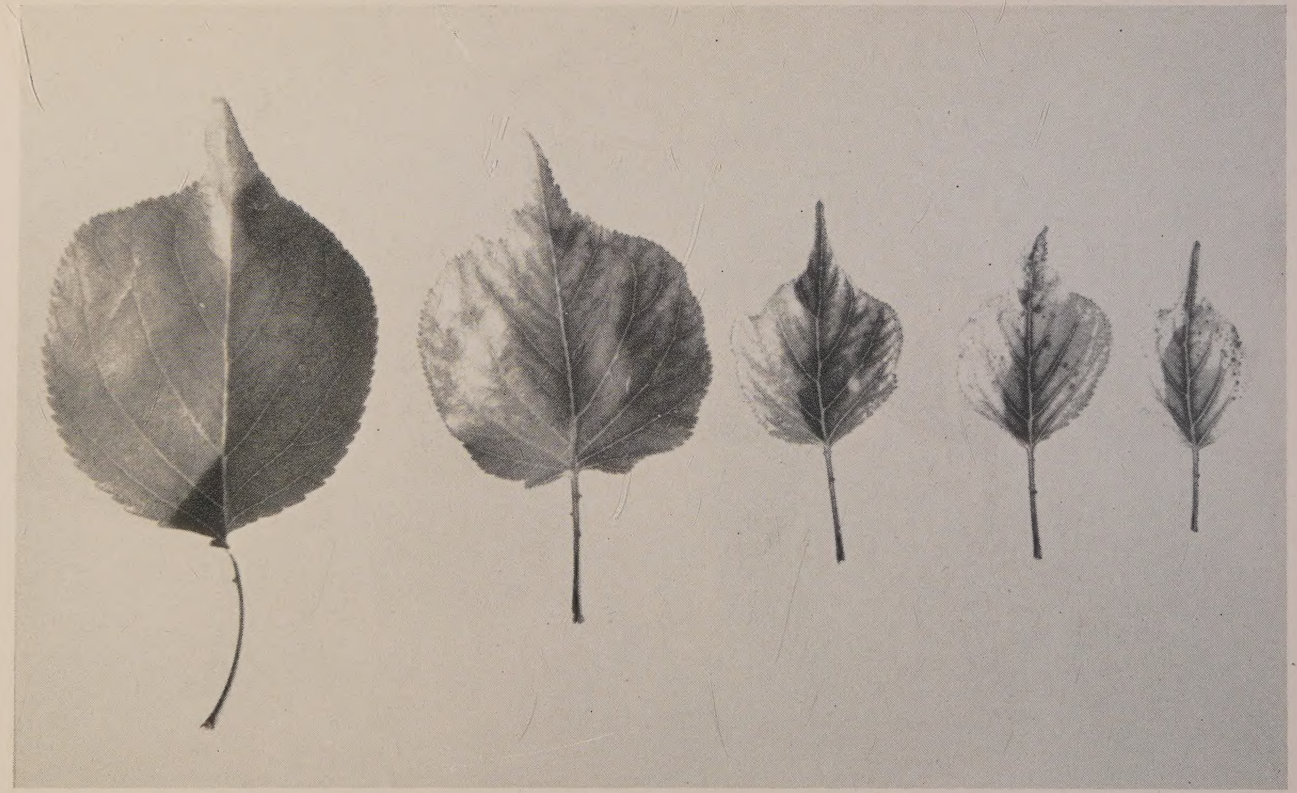

FIGURE 9. Apricot leaves affected with zinc deficiency. The leaf on the left is normal. The others show varying degrees of severity of the deficiency.

had applied his regular cover sprays of DDT and parathion. In the spring of the following year the buds on the sprayed trees opened before those on the unsprayed checks and maintained a slight lead until the leaves matured. In other trials, zinc oxide was mixed with some of the insecticides (DDT and malathion) currently being used in order to study their compatabilities. There was no damage to the leaves or fruit on the treated trees and no visible lack of control of insects. The effects produced by the use of this chemical are slight and they are insufficient to consider using it to effect a cure. It is, however, recommended that zinc oxide be used at the rate of two pounds per acre or one-quarter pound per 100 gallons as a preventive spray. In one orchard that was formerly severely affected, it has been shown that this amount applied annually will prevent the recurrence of zinc deficiency for at least two years. It has been reported (3) that zinc oxide, if used in large amounts (5 to 10 pounds per acre), with certain insecticides, or under unfavourable (cold and wet) weather conditions, may cause a russet on some varieties of apple, particularly Golden Delicious.

During the course of these investigations, injection methods for the control of zinc deficiency were tried. Two procedures were used, viz. (*a*) driving zinc coated nails or glazier's zinc coated points into the trunks or large limbs of affected trees, and (*b*) placing gelatin capsules containing zinc compounds into holes drilled into affected trees. There was a slow but slight response to the former, but it was not considered worthwhile for general use. The injection of zinc compounds was more effective but care had to be exercised with the choice of material, the depth of placement, and the sealing of the hole. In one trial zinc acetate and zinc sulphate were

TABLE 2.—ZINC CONTENT OF APPLE LEAVES FROM TREES GROWING IN PLOTS TREATED WITH ZINC SULPHATE

(p.p.m. on an air dry weight basis)

Sample No.	Treatment	Zinc content
3–161	$ZnSO_4 . 7H_2O$, 20 lb./tree, 1951, 1952	17.2
3–162	$ZnSO_4 . 7H_2O$, 20 lb./tree, 1951, 1952	15.6
3–163	$ZnSO_4 . 7H_2O$, 20 lb./tree, 1951, 1952	15.8
3–164	$ZnSO_4 . 7H_2O$, 20 lb./tree, 1951, 1952	17.7
3–165	$ZnSO_4 . 7H_2O$, 20 lb./tree, 1951, 1952	17.0
3–176	None	16.0
3–177	None	15.4
3–178	None	20.3
3–179	None	25.0
3–180	None	13.9

used on May 18 and the materials dissolved in the sap so readily that leaves on upper branches were burnt and fell off. On the other hand, relatively insoluble compounds, such as zinc borate and zinc oxide, did not disappear from the holes in which they had been placed even though the gelatin capsule had disintegrated. For general practice this method did not seem suitable for recommendation to growers.

Soil applications of zinc sulphate, 20 pounds $ZnSO_4 . 7H_2O$, scattered within the limb spread of mature apple trees, were tried for two successive years on the same plots. In one of three orchards selected for this trial a permanent type of cover crop was growing and after the second application the vegetation showed signs of severe burning and many plants died. There was no increase of zinc in leaves from treated trees when compared with the amount present in leaves from adjacent untreated trees (Table 2). In the remaining two orchards there was no cover crop and the trees were showing symptoms of medium to severe zinc deficiency at the time of application. The treatments were not effective in that they did not alter or reduce the symptoms of the deficiency.

DISCUSSION

The essential nature of zinc for the growth of plants has been recognized for almost three decades, but deficiencies of this element in the interior fruit-growing areas of British Columbia have been observed for only a few years (13). The delay in recognition may have been due to several factors among which the following may be mentioned: the similarity of patterns due to either zinc or manganese deficiency particularly in stone fruits; the similarity of position of leaves affected with either or both zinc and iron deficiency; the possibility of the presence of other physiological disturbances, e.g. arsenic toxicity, and the possibility that the supply of available zinc has been slowly used up. The syndrome of zinc deficiency has been found on many types of fruit (apple, pear, peach, apricot, cherry, and prune) and in many orchards in the Okanagan and adjacent valleys.

The pH of the soil in which the affected trees are growing varies from 5.5 to 7.5 and since addition of rather large amounts of zinc sulphate (20 pounds per tree for each of two successive years) to the soil did not alleviate the deficiency it appears that the zinc must be tied up before it penetrates to the root zone. This contention is in agreement with statements by Benson (2) who claims that soils have a strong affinity for zinc, and that shortly after this material is added to a soil it is irreversibly absorbed into the crystalline structure of soil minerals. Because of this tie-up, the supply of zinc to trees affected with a deficiency is best supplemented by applying zinc-containing compounds to the aerial parts. Experimental results and field observations have shown that soil applications were not satisfactory in increasing the amount of zinc or in lessening the severity of the symptoms in leaves from trees growing in treated areas.

The use of zinc sulphate as a dormant spray for the cure of zinc deficiency in fruit trees has become a standard practice in many fruit-growing areas where zinc deficiencies are found. One application of this spray may prevent the deficiency in some orchards but in others further applications in following years may be required. Observations have shown

FIGURE 10. Severe zinc deficiency in peach has caused a loss of many of the leaves and only a few small distorted ones remain near the tip of affected branches.

FIGURE 11. On this peach branch severe zinc deficiency has caused a marked stunting. The lateral branches have failed to develop; many leaves are small, chlorotic, and distorted.

that, once a zinc deficiency has been prevented by the use of one or more dormant sprays, deficiency symptoms did not reappear for two years. It must be obvious, then, that the amount of zinc within the tree must be decreasing and at some time it must be lower than optimum for the most vigorous growth of the tree and production of good quality fruit. It would therefore appear to be of benefit to apply a small amount of zinc annually in order to maintain a satisfactory amount of this micro-nutrient in a tree. With this in mind, the possible use of zinc oxide as a foliage or summer spray was studied. Within the limitations as already outlined this material proved to be satisfactory for this purpose and is now being used as a preventive spray at the rate of two pounds per acre in most orchards in the Okanagan Valley.

The results of analyses, determined by the dithizone method, A.O.A.C. (first action) (1), indicated that the zinc content of healthy apple leaves varied from 9.6 p.p.m. to 29.4 p.p.m. on a dry weight basis, and that of leaves from trees on which some leaves were showing a deficiency pattern from 2.0 p.p.m. to 12.8 p.p.m. Corresponding figures for *peach* were 9.9 p.p.m. to 30.4 p.p.m. and 5.3 p.p.m. to 13.4 p.p.m.; for *cherry* 13.1 p.p.m. to 23.9 p.p.m. and 6.2 p.p.m. to 15.1 p.p.m.; and for *apricot* 12.5 p.p.m. to 23.4 p.p.m. and 5.3 p.p.m. to 11.1 p.p.m., respectively.

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks to H. R. McLarty, Officer-in-Charge, Summerland Plant Pathology Laboratory, for his interest and assistance during the course of these investigations and the preparation of the manuscript; and to S. R. Cannings, of the Plant Pathology Laboratory, for the photographic work.

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WEATHER CONDITIONS INFLUENCING WHEAT YIELDS IN TANKS AND FIELD PLOTS[1]

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[Received for publication March 8, 1954]

ABSTRACT

Thirty-one years' measurements of the influence of meteorological factors on the yield of spring wheat grown in tanks and on field plots are described. Evapotranspiration, the sum of the stored moisture used from the soil plus the seasonal rainfall, was the most important single factor influencing crop yield. Stored moisture and rainfall were almost equally effective under the conditions of these experiments.

Linear regression between yield and evapotranspiration showed that the yield was increased by approximately 4 bushels per acre for each additional inch of water used. When the evapotranspiration was less than 5 or 6 inches no grain was produced. The distribution of the field plot data was significantly curvilinear, indicating a greater increase in yield per inch of water used for high evapotranspiration.

Yields of wheat on plots were reduced significantly by above normal air temperature or evaporation. The yields in tanks were reduced significantly by high temperatures but not by high evaporation alone.

Multiple correlation coefficients between yield and the various moisture and weather factors of 0.92 for tanks and 0.95 for field plots showed that appreciable variability remained unaccounted for. Part of this was attributed to variations in weather conditions during critical growth periods.

Soil moisture tanks and field plots have been used at Swift Current since the early 1920's to study the relationships between crops and precipitation. Crops are grown in the tanks, 15 inches in diameter and 5 feet deep, in rotations simulating the cultural treatments practised by farmers in the surrounding districts. Although tank crops yield consistently higher than those grown in the open field, the conservation and use of moisture, and the response to varying weather conditions closely parallel field performance.

Experimental plots are more representative of field conditions than are the tanks. Even here, because of variations in soil texture, exposure, snow accumulation and weed growth the soil moisture conditions in small plots may not always equal the average in large fields. However, results from experimental plots give reliable data on the efficiency of moisture use in bushels of grain per inch of water used, whether or not the actual yield is a good average for the district.

The present paper is an analysis of the effects of precipitation, stored moisture, free-water evaporation, and other factors, on the yield of wheat grown in tanks and on field plots.

REVIEW OF LITERATURE

The amount of water used by crops growing with ample supplies of moisture was calculated from meteorological data by Penman (10), Thornthwaite (15), Blaney and Criddle (3) and others. Penman calculated

[1] Contribution from the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Canada.

[2] Physicist and Soil Physicist, respectively.

the evaporation loss from a free-water surface on the basis of air temperature, humidity, solar radiation and wind velocity, and showed that the use by crops in summer was 80 per cent of the free-water loss. Thornthwaite and Blaney used two different formulae based on air temperature and hours of sunshine. These methods provide an upper limit or the potential evapotranspiration which is rarely reached in southern Saskatchewan because shortage of moisture is a limiting factor almost every season. Evapotranspiration or consumptive use formulae give estimates of the amount of water required to produce the maximum yield, whereas in dry-land farming the emphasis is on the yields that can be produced with the precipitation and stored moisture available.

Connor (6) and Hopkins (8) (9) studied the relationship between the yield of spring wheat and precipitation on the Canadian Prairies. Cole and Mathews (4), Blair (2) and Davis and Pallesen (7), made somewhat comparable analyses for the Great Plains of the United States. The response of wheat to stored moisture and precipitation at Swift Current, Saskatchewan, was discussed in a report of the Soil Research Laboratory (12). The results from the various sources show that, in general, the highest correlations between yield and precipitation were obtained in the drier districts where moisture deficits occurred most frequently. Yields were usually more highly correlated with seasonal than with annual precipitation, and with seasonal precipitation plus stored water than with seasonal or annual precipitation alone. The latter might be expected because it is known (5) that crop yield is highly correlated with the stored moisture at seeding time, and the storage from pre-seasonal precipitation is variable and often very low (13).

METHODS

Tank Crops

The tanks used in this work were 15 inches in diameter and 5 feet deep, and contained 600 lb. of soil added in layers simulating the profile found in the field. The soil was Haverhill clay loam, with field capacity about 22 per cent. Except for certain irrigation projects the crops were grown on natural precipitation only. Weeds were removed from both fallowed and cropped tanks, and wire cages reduced losses due to wind, hail, birds and rodents. The amount of moisture used by crops in tanks was obtained by weighing the tanks at seeding time, at intervals throughout the growing season and again at harvest. The stored moisture used by the crop was the difference between the spring and harvest weights. Usually the crops had exhausted all of the available soil moisture by harvest time. The total water used (evapotranspiration) was that removed from the soil plus the precipitation received during growth of the crop. Losses from run-off and deep percolation were prevented in the tank method. Records of rainfall, free-water evaporation, air temperature and hours of sunshine were obtained adjacent to the experimental area. The free-water evaporation was measured in a tank 4 feet in diameter and 2 feet deep, set into the ground to within 2 inches of the rim.

The tank data reported are from a 2-year rotation of summerfallow-wheat; a 3-year rotation of summerfallow-wheat-wheat; and continuous

cropping to wheat. The replication in the early days of the project was 2 tanks per treatment, but this was increased to 4 in 1937 and to 6 in 1948. Data from some other tanks which had received comparable treatments were included with the above rotations to give moisture and yield results for 8 fallow crops and 8 stubble crops each year for the 31-year period 1922-52, inclusive.

Field Crops

Field data were obtained from plots and strips on which different methods of working summerfallow and of preparing stubble land for seeding were tested. Results were taken only from treatments which were accepted as good farming practices. The size of the plots, the site of the experiments and the methods of soil and crop sampling were changed a number of times during the period under study. From 1925 to 1936 data were obtained from triplicated fiftieth-acre plots on Haverhill loam. Lack of uniformity in soil texture resulted in a high sampling error on some of these plots. In 1937 the treatments were moved to 5-acre strips on uniform Wood Mountain clay loam. Five strips of both summerfallow and stubble crop were sampled from 1937 to 1942, after which the sampling was reduced because of war shortages. The project was revised again in 1946, and since that time samples have been obtained on two fields each of fallow and stubble crop.

The best mean yearly values available for stored moisture and yield were used. The moisture data were obtained from a minimum of 6 sites sampled to a depth of 4 feet. Samples were taken at seeding time and harvest, the difference in moisture content being the amount of stored moisture used by the crop. The volume weight or apparent specific gravity of the soil was determined so that percentage moisture contents could be converted to inches of water. From 1925 to 1940, inclusive, yields were obtained by harvesting the whole plot or strip. Subsequent to 1940 yields were obtained from duplicate square yard samples of crop taken near each moisture sampling site. The latter results were included also as part of the substation program (14). Altogether, 28 years' results (1925-52) for both fallow and stubble crops were available for analysis.

RESULTS

31-Year Averages of Weather and Soil Moisture Data

The mean annual precipitation at Swift Current for the period 1922-52, inclusive, was 13.65 inches. Fortunately, approximately one-half (6.31 inches) was received during May, June and July when it was needed most for growing crops. The seasonal rainfall varied widely, and because of a few very wet years, it was below the average more than half the time or about 6 years out of 10. Crop failures resulted when both stored moisture and seasonal rainfall were low.

Mean meteorological data for the growing season at Swift Current 1922-52 are given in Table 1. The month of August was included because in late seasons efficient use may be made of August rains. The table shows that the maximum precipitation occurred in June and the maximums of

TABLE 1.—MEAN METEOROLOGICAL DATA FOR SWIFT CURRENT DURING THE GROWING SEASON, 1922-52, INCLUSIVE

		May	June	July	August
Precipitation (in.)		1.54	2.87	1.90	1.80
Sunshine (hr.)		238.3	229.3	303.9	256.6
Air temperature	Mean max. (° F.)	62.6	70.5	79.9	76.9
	Mean min. (° F.)	37.7	47.0	52.5	48.9
	Mean (° F.)	51.8	58.8	66.0	62.7
Free-water evaporation (in.)		5.47	5.72	7.31	6.29

sunshine, temperature and evaporation occurred in July. The mean free-water evaporation for May through July was 18.50 inches compared with 6.31 inches precipitation for the same period. The evapotranspiration for crops amply supplied with moisture is approximately 80 per cent of free-water evaporation (10). Since the average loam soil will hold only 6 inches of water within the 4-foot root zone for an appreciable length of time, it appears that wheat crops on summerfallow at Swift Current will rarely have more than two-thirds the optimum required. In other words, the crops are usually grown under soil moisture stress, and the yields are reduced accordingly.

The mean yield, soil moisture and weather data for crops grown in tanks and on field plots at Swift Current are given in Table 2. Most of the yearly results for the tank crops have been published previously (12). Precipitation was based on the dates of spring and harvest sampling in each case. Evaporation, temperature and sunshine were computed on the basis of average seeding and harvest dates for the different seasons. The tank yields were consistently higher than those on field plots. This was due partly to a greater conservation of moisture, and partly to a greater efficiency in the use of moisture by crops in tanks. Factors such as the control of weeds and the prevention of run-off increased both conservation and efficiency. Greater uniformity of stand, higher soil temperature and better root distribution probably also contributed to the yields in tanks.

The stored moisture used by fallow crop in tanks, 5.35 inches, was about an inch greater than that used by similar crops on Experimental Substations in southern Saskatchewan (13). This was due largely to the prevention of drainage below the root zone and elimination of run-off and weed growth. These factors would be offset to some extent by lower than average snow accumulation in the tank area. The mean stored moisture used by stubble crop in tanks, 2.43 inches, was only slightly above that normally observed in farmers' fields. The stored moisture used by fallow crop in the field, as shown in the lower half of Table 2, was considered normal for the area, but that used by stubble crop was above normal. The latter is believed to be due in part to excess snow accumulation on the sites chosen for stubble treatments. This should not lessen the value of the data in the present case where yields and moisture use are correlated.

TABLE 2.—MEAN YIELD, SOIL MOISTURE AND WEATHER DATA FROM SEEDING TIME TO HARVEST

		Yield Y	Precipitation P	Stored moisture used S	Total moisture used M	Free-water evaporation E	Mean air temperature T	Sunshine H
		bu/ac.	in.	in.	in.	in./day	°F.	hr./day
Tanks, 1922-52	Fallow crop	31.0	6.31	5.35	11.66	0.208	60.7	8.6
	Stubble crop	17.7	6.21	2.43	8.64	0.208	60.7	8.6
	Mean	24.3	6.26	3.89	10.15	0.208	60.7	8.6
Field plots, 1925-52	Fallow crop	16.9	5.96	3.90	9.85	0.212	60.8	8.8
	Stubble crop	12.5	5.74	3.12	8.86	0.212	60.8	8.8
	Mean	14.7	5.85	3.51	9.36	0.212	60.8	8.8

The mean growing season for the tank crops was about 95 days, roughly from mid-May to mid-August. The season for the field crops was somewhat longer as they were less exposed, and did not develop as rapidly. When evapotranspiration for tank crops was plotted against time throughout the season, the resulting curve was "S" shaped with the mean moisture use approaching free-water evaporation during the period June 16-30. At this time the crop had usually reached maximum leafage and moisture supplies were still available in the soil. The greatest efficiency in the use of moisture was observed in years such as 1942 when evapotranspiration was low in May and June, and high during heading and filling in July. A reduction in the use of moisture before late July usually resulted in lower efficiency, i.e., lower yields for the amount of water used.

Relation of Yield to Total Evapotranspiration

Scatter diagrams showing the yield of wheat Y plotted against total evapotranspiration M for tank and field crops are shown in Figures 1 and 2. Comparison of these diagrams confirms the greater efficiency in use of moisture by the tank crops. In each case there appears to be little difference in the distribution of experimental points for fallow and stubble

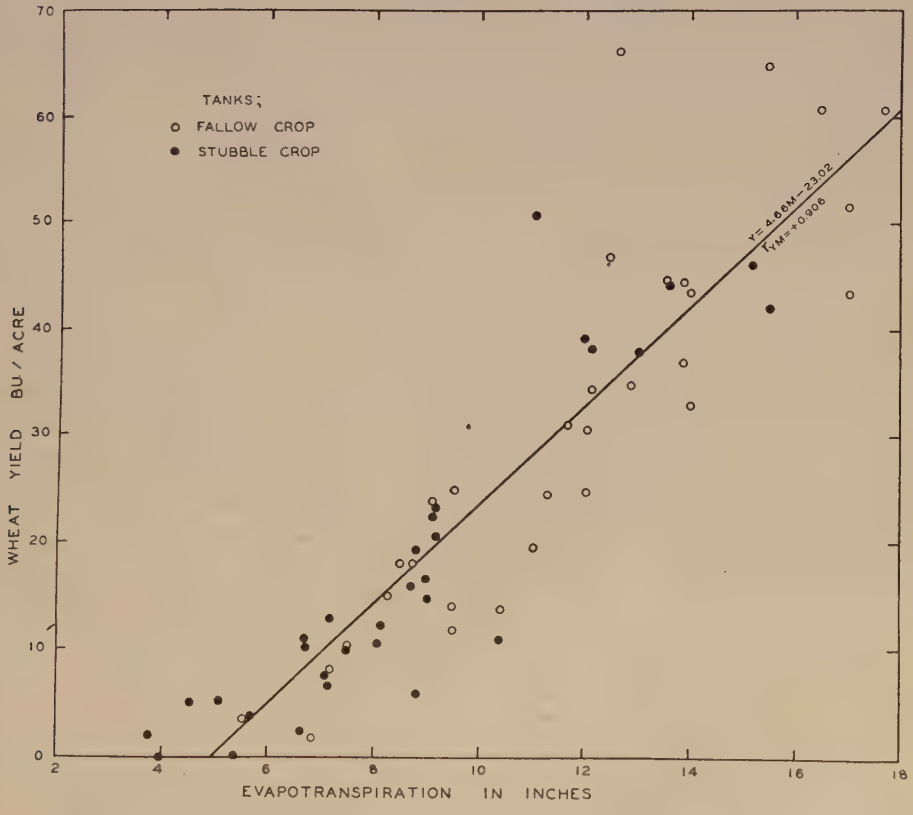

FIGURE 1. Relationship between wheat yield and evapotranspiration in tanks, 1922-52.

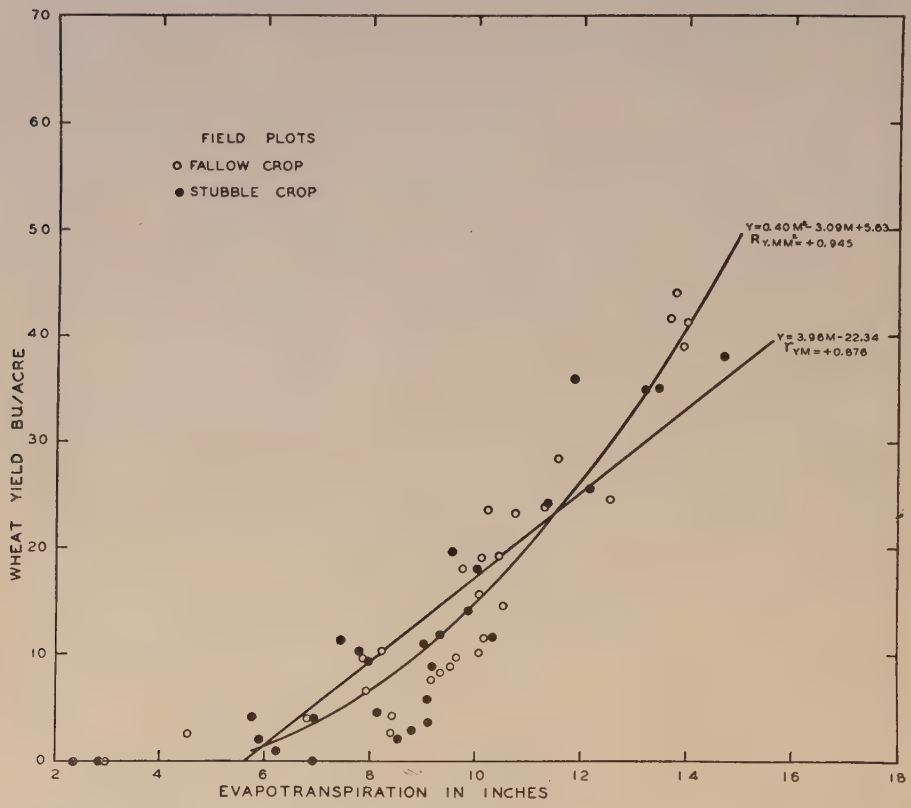

FIGURE 2. Relationship between wheat yield and evapotranspiration on field plots, 1925-52.

crops. The low yields obtained for some stubble crops in the field were due to poor germination and weed growth in the drier years.

Table 3 shows the correlation and linear regression data obtained. The correlation coefficients for the combined fallow and stubble crops in both tank and field were approximately 0.9 and were highly significant. The regression coefficients show that yield was increased 4.66 bushels per acre for each additional inch of water used by tank crops compared with 3.96 bushels per acre per inch for field crops. The intercept of the regression line on the moisture axes showed that 4.93 inches of evapotranspiration were required to produce any yield whatever in the tanks, whereas 5.64 inches were required in the field. This means that these quantities of water were used in establishing the wheat plant and unless they were exceeded no yields were obtained.

The regression coefficients were higher for fallow than for stubble crop in both tanks and field plots, although in neither case were the differences significant. Likewise, the yields of fallow and stubble crops were not significantly different after differences in moisture use were corrected for on the basis of the linear regression. Apparently differences in fertility or soil structure associated with these crops did not have an important influence

TABLE 3.—THE RELATIONSHIP BETWEEN CROP YIELD AND EVAPOTRANSPIRATION

		Correlation coefficient, r_{ym}	Regression coefficient, b_{ym}	Constant in regression equation
Tanks	Fallow crop	0.883**	4.99	− 27.23
1922-52	Stubble crop	0.903**	4.45	− 20.74
	Combined	0.906**	4.66	− 23.02
Field plots	Fallow crop	0.886**	4.37	− 26.16
1925-52	Stubble crop	0.864**	3.61	− 19.45
	Combined	0.876**	3.96	− 22.34

** Significant at 1 per cent level.

on yield. It is true, of course, that the water requirement, viz., evapotranspiration divided by yield, was higher on the average for stubble crops than for fallow, but this is explained by the lower average available moisture in stubble, and the fact that the linear relationship between yield and evapotranspiration does not pass through the origin.

The addition of a quadratic term M^2 improved the estimate of yield significantly for the field plots but not for the tanks. The curvilinear regression line for the plots is shown in Figure 2. If the three points in the lower left hand corner of this figure, representing crop failures on plots for evapotranspiration less than 3 inches, are omitted, the correlation coefficient between Y and M is increased from 0.876 to 0.911 and the linear regression is correspondingly improved. The contribution of the M^2 term remains significant, however, whether or not the three points are omitted.

Relation of Yield to Precipitation, Stored Moisture and Free-water Evaporation

From field observation it seemed possible that the response of yield to seasonal rainfall would be different from the response to the same amount of stored moisture used. In a further analysis, the correlation of yield with precipitation P and moisture used from the soil S were worked out separately. Also, since a number of the meteorological factors affecting the crop probably influence evapotranspiration in much the same way as they do free-water evaporation E, the latter was chosen as a third variable to correlate with yield. The simple and partial correlation coefficients obtained for tank and field data are given in Table 4.

Highly significant simple correlations were obtained between yield and both precipitation and stored moisture used by tank and field crops. High negative correlations were obtained between vield and free-water evaporation for both sets of data. The simple correlations between precipitation and stored moisture used were negligibly small in both cases. The correlation between stored moisture and free-water evaporation was negative, and short of significance for the tanks but highly significant for the field plots.

TABLE 4.—SIMPLE, PARTIAL AND MULTIPLE CORRELATION COEFFICIENTS BETWEEN YIELD Y, PRECIPITATION P, STORED MOISTURE S, AND FREE-WATER EVAPORATION E

Simple correlation			Partial and multiple correlation		
	Tanks	Field plots		Tanks	Field plots
YP	0.663**	0.778**	YP.S	0.862**	0.847**
YS	0.550**	0.435**	YS.P	0.825**	0.647**
YE	− 0.627**	− 0.742**	Multiple Y.PS	0.906**	0.878**
PS	− 0.097	0.036	YP.SE	0.764**	0.696**
PE	− 0.671**	− 0.679**	YS.PE	0.801**	0.531**
SE	− 0.222	− 0.424**	YE.PS	− 0.016	− 0.175
			Multiple Y.PSE	0.906**	0.882**

** Significant at 1 per cent level.

The relationships between yield and precipitation, stored moisture and evaporation are complicated by association between the various factors. The partial correlation coefficients in columns 5 and 6 of Table 4 gave a truer picture of these relationships when the effects of other associated variables were held constant. The coefficients $r_{yp.s}$ and $r_{ys.p}$ were high, largely because seasonal precipitation and stored moisture were complementary in their influence on yield. The partial coefficients $r_{yp.se}$ and $r_{ys.pe}$ showed that the correlations between yield and moisture use were reduced somewhat when independent of evaporation effects. The partial coefficients relating yield with rainfall and with stored moisture were about equal for the tanks, but the correlation with rainfall exceeded that with stored moisture for the field plots.

An important feature of the results was the low partial correlation coefficients between yield and free-water evaporation for both the tank and field data when the effects of P and S were held constant. This is taken to mean that the effects of seasonal differences in humidity, wind speed, etc., on wheat yield are not large compared with experimental errors, when crops are grown under the moisture conditions in the Swift Current district. This does not preclude the possibility that humidities and temperatures producing high evaporation for short periods may cause serious damage to the crop without influencing the seasonal average evaporation appreciably.

Another unexpected result derived from Table 4 was that equally good estimates of yield, both in tank and field, could be obtained on the basis of total evapotranspiration only, without considering P and S separately. The correlation between Y and M for the tanks was 0.906 and for the field 0.876, whereas using factors P, S and E, the multiple correlation for the tanks was only 0.906 and that for the field plots 0.882. In other analyses of wheat yields from two-year rotations in tanks and on

experimental substations (12) (14) significant reductions in the error variance resulted when P and S were used as separate variables.

The negative partial correlation between yield and evaporation ($r_{ye.ps}$) in Table 4 was greater for the plots than for the tanks. Similar non-significant coefficients were obtained when E was considered with M only ($r_{ye.m}$). But when E was included in the regression equation for plot yields involving M^2 as well as M, the residual variance was reduced significantly. The resulting equation was

$$Y \text{ (plots)} = 0.41\ M^2 - 4.08\ M - 76.60\ E + 29.90$$

where M was the total evapotranspiration from seeding to harvest, and E was the mean daily free-water evaporation for the same period.

In contrast with the above, the addition of M^2 and E to the regression equation for tank yields did not reduce the error variance significantly.

Relation of Yield to Air Temperature and Hours of Sunshine

Air temperature and hours of sunshine might be expected to influence crop growth directly because of the requirements and tolerances of plants, and indirectly because of influence on moisture use. Analysis showed that the plot yields were negatively correlated with air temperature when the latter variable was considered instead of free-water evaporation, but the inclusion of temperature as well as evaporation in the regression was not justified. The regression equation for the plot yields, therefore remained unchanged.

Crop yields in tanks were negatively correlated with air temperature T, and the resulting regression equation was

$$Y \text{ (tanks)} = 4.41\ M - 1.17T + 50.60\ .$$

The yields of neither field nor tank crops were significantly correlated with hours of sunshine.

Factors Influencing Evapotranspiration by Tank Crops

The low partial correlation of yield with free-water evaporation in Table 4 suggested the need for further study of the mechanism of moisture use by dry-land crops. Table 5 shows partial correlation coefficients between evapotranspiration by fallow wheat in tanks and free-water evaporation E, precipitation P and moisture content C for six 15-day periods beginning May 17. The partial correlation coefficients between moisture used and free-water evaporation were positive during the first three periods and negative during the last three periods. Only in the first, second and last 15-day periods were the correlations significant. The positive correlations in May and early June were probably the result of surface evaporation and relatively high initial supplies of moisture. The negative correlation in August follows from the fact that when evaporation was high, crops ripened prematurely, and conversely, when free-water evaporation was low, crops continued to use moisture during part of August. For the important period from June 16 to July 31, the correlation coefficients were low and tended to be negative.

TABLE 5.—PARTIAL AND MULTIPLE CORRELATION COEFFICIENTS BETWEEN EVAPOTRANSPIRATION FROM TANKS M AND FREE-WATER EVAPORATION E, PRECIPITATION P, AND INITIAL SOIL MOISTURE CONTENT C FOR 15-DAY PERIODS, 1922-51, INCLUSIVE

Period	ME.PC	MP.EC	MC.EP	Multiple M.EPC
May 17–31	0.448*	0.180	0.481**	0.608*
June 1–15	0.397*	0.361	0.418*	0.467*
June 16–30	0.065	− 0.059	0.725**	0.757**
July 1–15	− 0.175	0.243	0.666**	0.821**
July 16–30	− 0.097	0.670**	0.957**	0.969**
July 31–August 14	− 0.425*	− 0.129	0.542**	0.739**

* Significant at 5 per cent level.
** Significant at 1 per cent level.

The high correlation coefficients between evapotranspiration and soil moisture content emphasized that available moisture was the controlling factor. Even precipitation was not significant except in the late July period when normally the supplies of stored moisture were exhausted. Precipitation was much more important than appears at first sight, however, because the stored moisture C at the beginning of each 15-day period included much of the precipitation received during the previous period.

The data in Table 5 stress the limited part that mean free-water evaporation plays in the evapotranspiration from wheat in tanks at Swift Current. Various authors (1) (10) (16) have shown that evapotranspiration for crops with ample supplies of moisture is proportional to the free-water loss. The relationship is undoubtedly more complicated in districts where the available water is only two-thirds of the free-water evaporation. It appears probable, as Penman (11) has suggested, that the removal of moisture by plants growing in a soil with a low moisture supply, decreases as the soil dries out, in a manner analogous to the decrease of evaporation from bare summerfallow. Plant adaptation under moisture stress may make transpiration losses correspondingly insensitive to the evaporating conditions of the atmosphere.

DISCUSSION AND CONCLUSIONS

As far as crop yields were concerned, the present analysis dealt with average seasonal effects only, neglecting the distribution of weather conditions through the growing season. It is known, for instance, that in some seasons the distributions of precipitation and temperature are critical in the development of the crop. These effects will be considered in a further analysis.

The results showed that tank and field crops responded similarly to moisture supply and mean weather conditions, evapotranspiration M being the most important single factor influencing yield in each case. The two components of M, viz., seasonal rainfall and stored moisture used, had

nearly equal influence on yield. Both P and S are closely associated with the meteorological and soil factors controlling plant growth and their separate contributions are worth investigating because of differences in these relationships under different seasonal conditions.

The linear regression coefficients obtained between yield and either evapotranspiration or seasonal rainfall were somewhat higher than those reported by Hopkins (8) (9). The values in Table 3 are approximately 4 bushels per acre for each inch of moisture used, whereas Hopkins obtained coefficients of 1 to 3 bushels per acre for each additional inch of seasonal precipitation. Cole and Mathews (4) reported regression coefficients varying from 2.5 to 5.0 bushels per acre for each extra inch of water used.

The yield vs. evapotranspiration relationship for the field plots (Figure 2) was curvilinear, with the yield per inch increasing with higher moisture use. Similarly on substations (14) the increase in yield per inch of water used increased with the amount of total evapotranspiration. In contrast with this, the tank data in Figure 1 show no appreciable curvilinear effect. The yields in both tanks and plots must reach a maximum for values of M corresponding to the maximum consumptive use or potential evapotranspiration for wheat at Swift Current (17 to 19 inches).

The influence of free-water evaporation on yield was low when differences due to variations in moisture use were eliminated. The partial correlation coefficients were negative, and the coefficient for field data was more than 10 times that for the tanks. Air temperature and free-water evaporation were closely related as far as the moisture economy of the plant was concerned. Either of these factors made significant negative contributions in the curvilinear regression equation for plot yields when the other variables were M and M^2. On the other hand, in the regression equation for tank yield, the inclusion of air temperature T was highly significant when used with M whereas, as mentioned above, the contribution of evaporation E was small and non-significant. These differences between crop response in tanks and field have not been explained.

Preliminary analyses of moisture use during different periods of crop growth in tanks showed that, when crops were grown under moisture deficits, moisture supplies influenced evapotranspiration much more than did the evaporating conditions of the atmosphere.

The highest multiple correlation coefficients obtained between yield and weather factors, 0.92 for tanks and 0.95 for field plots, show that appreciable variability in wheat yield remains unaccounted for by the mean seasonal moisture and weather data considered thus far. Part of this is believed to be due to critical variations in weather conditions during the season, and part to experimental errors.

ACKNOWLEDGMENTS

Many members of the Soil Research Laboratory and Experimental Station staffs contributed at various times to the experiments summarized in this report. The tank experiments and plot sampling were initiated and carried on for many years by the late S. Barnes and his assistant

A. C. Budd. The field work was part of an experimental program conducted in co-operation with P. J. Janzen and other members of the Field Husbandry division of the Experimental Station. J. L. Doughty, Officer-in-Charge of the Soil Research Laboratory, gave constant help and advice in the experimental work and in the preparation of the report.

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COMPARATIVE GROWTH STUDIES OF FLAX VARIETIES[1]

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[Received for publication May 6, 1954]

Observations have indicated that flax varieties differ as to rate of growth. To verify these observations five varieties were grown in the field and weekly measurements were taken on growth in plant height and dry weight.

Significantly different relative rates of stem elongation were found to exist. The cycle of growth was separated into two periods, the first being terminated at blossoming. A decline in the relative growth rate was associated with delayed blossoming. High temperature and sunshine appeared to favour an increase in relative growth rate of dry weight but a decrease in the rate of elongation.

INTRODUCTION

This study was initiated in 1950 to determine the growth rates of linseed flax varieties and to study the degree with which they are associated with agronomic characters and environmental conditions. A part of this study presented herein is concerned with the cumulative height and dry weight analyses of five varieties sown at three different dates within the years 1950-52.

Several methods of expressing growth rate in plants are available and have been reviewed by Miller (8). The differential equation developed by Hammond and Kirkham (4) from the compound interest theory of Blackman (1) has been used in this study. This equation is

$$\frac{d\,w}{w dt} = r$$

where w is the weight or height of the plant at time t, and r the relative growth rate.

Differences in the growth rates of flax varieties have been suggested by several investigators. Klages (7) found that Bison and Linota differed in rate of growth of stem. The growth curves of Bison and Redwing indicated different growth trends and these differences occurred during the two years studied by Dunham (3). High temperatures according to Crooks (2) increased the rate of growth in height during the early period of growth. Tiver (9) found that low moisture treatments decreased the total plant weight and considered that this was due to the low assimilating ability of the leaves.

MATERIALS AND METHODS

Five linseed varieties of flax were chosen for this study on the basis of differences in maturity, height and size of seed. Redwing, C.A.N. 2140, is an early maturing variety with straw of medium length and small seed. Raja, C.A.N. 80, is similar to Redwing but the seed is quite large. Redwood C.A.N. 62, is late maturing, producing a high yield of seed of good size.

[1] Contribution No. 176, Cereal Crops Division, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Canada. Part of a thesis presented by the senior author in partial fulfilment of the requirements for the degree of Master of Science at McGill University.

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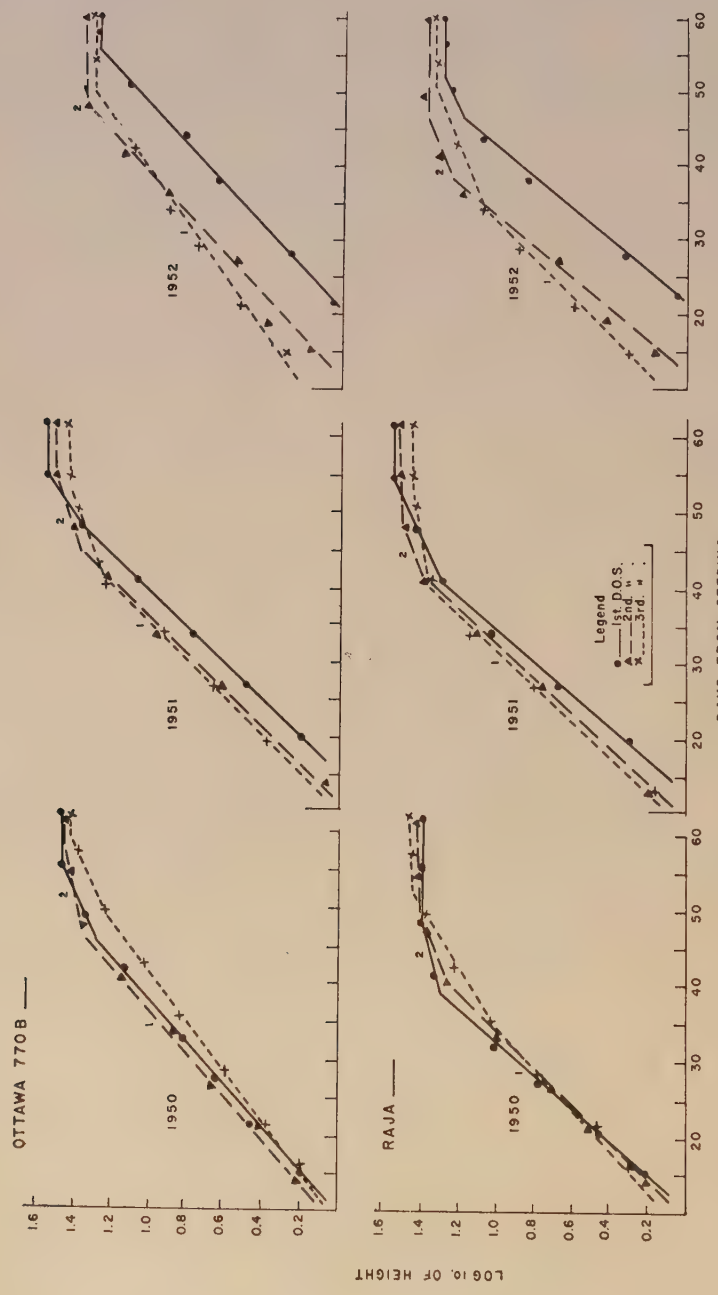

FIGURE 1. Logarithm of height measurements with days from seeding for the varieties Ottawa 770B and Raja in the years 1950-52, inclusive.

TABLE 1.—DATES OF SEEDING IN THE YEARS 1950, 1951 AND 1952

Test	Dates of seeding		
	1950	1951	1952
1	May 16	May 10	May 5
2	May 31	May 25	May 28
3	June 12	June 9	June 12

Ottawa 770B, C.A.N. 2152, is an erect growing, yellow seeded type also of late maturity. Ottawa 3693A, C.A.N. 114, is of medium maturity and yielding ability with very large seed. All varieties were replicated four times in 4 rod row plots with rows 9 inches apart and seeded at three dates in each year.

During the three growing seasons (1950, 1951 and 1952), the plant height was recorded at weekly intervals. It was determined by the average distance from ground level to the growing tip of the plants. Three measurements were taken for each of the four variety replications.

Dry weight data were obtained during the growing seasons of 1951-52 from an additional experiment replicated four times. At weekly intervals 2 feet of the two inside plant rows were harvested. The samples were dug with a large spade and care was taken to include all of the tap roots. The soil was removed by washing. From the harvested samples 50-100 plants were selected at random and then subjected to an initial drying treatment of 60°-70° C. for a period of 4-7 days, after which they received a final drying treatment of 90°-100° C., for 5 hours. The weights of the dry samples were recorded in grams. All the data cited are given on an individual plant basis.

EXPERIMENTAL RESULTS AND DISCUSSION

The growth curves for height of Ottawa 770B and Raja are represented by the graphs in Figure 1. The actual measurement for height, expressed in logarithms on the ordinate, are plotted against time on the abscissa. The graphs indicate that two growth periods occurred—one prior to flowering when the height increased at a uniform rate, and a second one associated with the flowering behaviour of the plants. The two are separated by a break in the curve which is believed to be due to the formation of fruiting branches. The other varieties displayed similar growth trends on height, and hence are not represented. Dry weight increase was similar in behaviour to height. Similar results were found by Heath (6) with cotton, and Hammond and Kirkham (4) with soybeans and corn. The change in the growth curve coincided with the dates when the plants began to bloom and the formation of tassels in corn.

ANALYSIS OF RELATIVE GROWTH RATES OF VARIETIES

The relative growth rate, i.e. rate of stem elongation, was obtained by multiplying the regression coefficient by 2.303*. The slopes of the

* The constant factor between natural and Napierian logarithms.

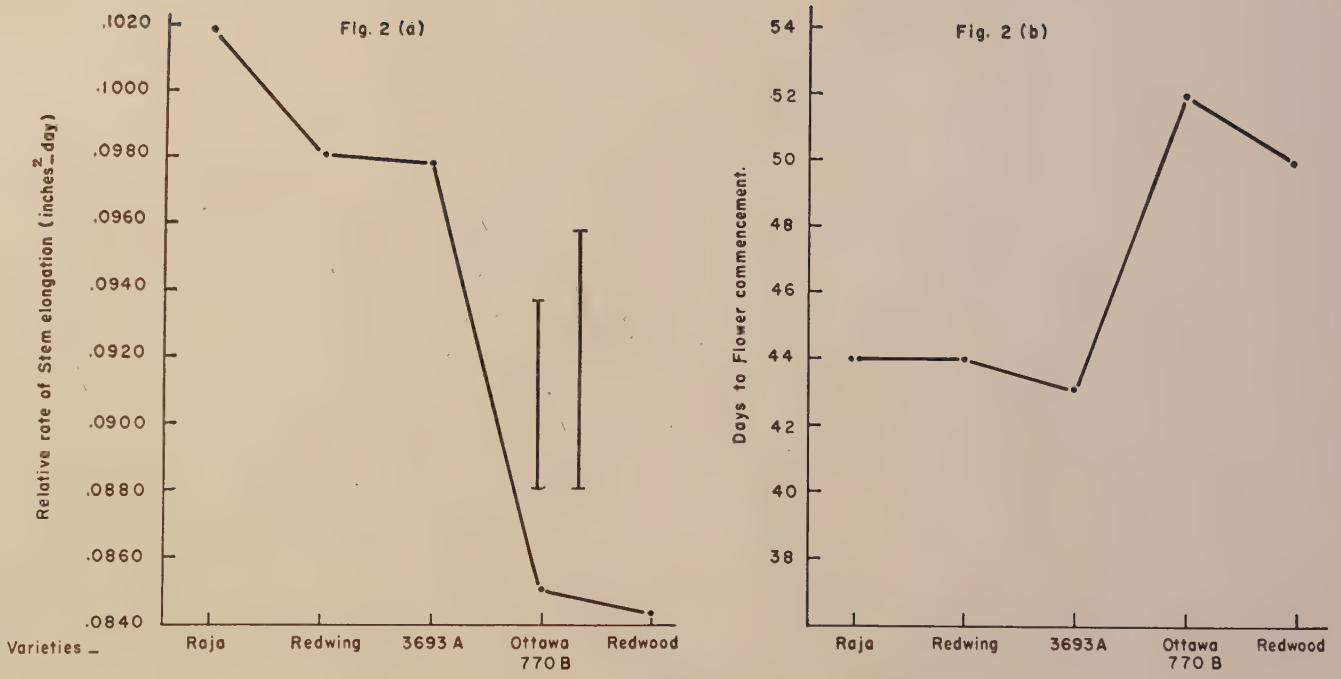

FIGURE 2 (a). Relative rate of stem elongation for each variety with the least significant difference between means at the 5 per cent and 1 per cent levels, respectively;
(b) average number of days to flowering for each variety.

TALE 2.—ANALYSES OF VARIANCE OF RELATIVE RATES OF STEM ELONGATION OF FIVE VARIETIES AT THREE DATES OF SEEDING (D.O.S.) IN EACH YEAR 1950-51-52, INCLUSIVE

Variation due to	Degrees of freedom	Mean squares ($\times 10^8$)
Varieties	4	59123.5**
D.O.S.	2	23509.0**
Years	2	26714.5**
V. × D.O.S.	8	6000.2
V. × Years	8	7624.5
D.O.S. × Years	4	3992.5
Error	16	2952.2

** Highly significant.

TABLE 3.—ANALYSES OF VARIANCE OF RELATIVE RATES OF DRY WEIGHT INCREASE OF VARIETIES AT THREE DATES OF SEEDING (D.O.S.) IN EACH YEAR 1951-52, INCLUSIVE

Variation due to	Degree of freedom	Mean squares ($\times 10^8$)
Varieties	4	88043.0
Years	1	191268.8**
D.O.S.	2	149615.5**
Var. × Years	4	39493.0
Var. × D.O.S.	8	27442.0
Years × D.O.S.	2	19351.0
Error	6	71668.0

** Highly significant.

regression lines of the first growth period for height and dry weight were calculated for all varieties. The significance of differences in varietal growth rates were tested by the analysis of variance and the three factor interaction of variety, date of seeding and years was used as the error variance. Tables 2 and 3 contain the results of the growth rate analysis of height and dry weight, respectively.

Varietal Differences

The varieties differed significantly in relative rate of stem elongation; the mean relative rate of elongation of each variety is plotted in Figure 2 (a). The significant variety variance appears to be due to a difference beween two groups, one containing Raja, Redwing, and Ott. 3693A, and the other

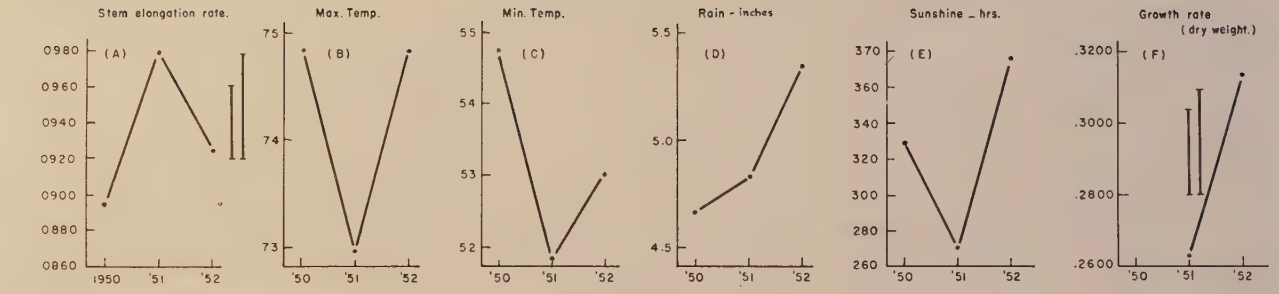

FIG. 3.

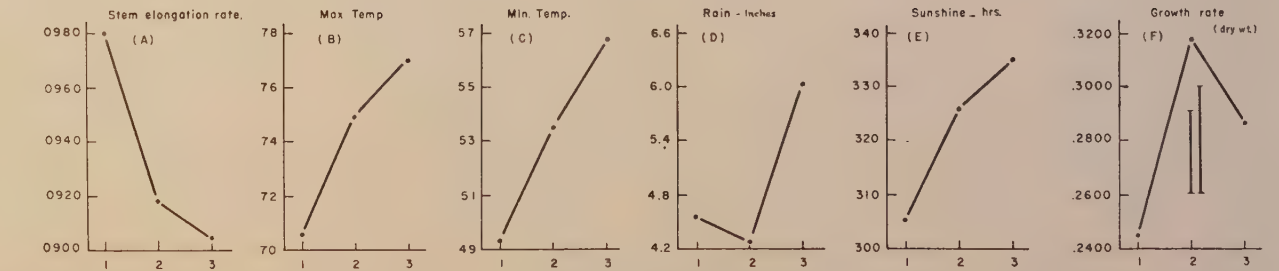

FIG. 4.

FIGURE 3. Annual means for the growing season in 1950-52 of rate of stem elongation in inches/day, maximum and minimum temperatures in degrees Fahrenheit, rainfall in inches, sunshine in hours and relative rate of increase in dry weight in cgm./day for years 1951-52.

FIGURE 4. Means of dates of seeding in 1950-52 for rate of stem elongation in inches/day, maximum and minimum temperatures in degrees Fahrenheit, rainfall in inches, sunshine in hours and relative rate of increase in dry weight in cgm./day for years 1951-52.

Ott. 770B and Redwood. On comparing the number of days to flowering of each variety (Figure 2 b), and the relative rate of stem elongation, a significant and negative correlation of 0.930 was obtained. From this it is assumed that the rate of growth in height is to a considerable extent associated with the flowering mechanism of the flax plant. In other words an early flowering variety can be expected to have a faster relative rate of stem elongation than later flowering types.

Seed size apparently was not associated with the relative rate of stem elongation since Ott. 3693A and also Raja are not significantly different in growth rate from Redwing, yet differ considerably in weight of seed. The respective seed weight values per thousand kernels are approximately 7.0 grams for Ott. 3693A, 6.4 grams for Raja, and 4.5 grams for Redwing.

The relative rate of dry weight increase of these varieties did not differ greatly as shown by the data in Table 3. A detailed study of the 1951 data (5) indicated that height and dry weight increase are not always associated. Tiver and Williams (10) found that a fibre and a linseed variety differed in this respect. The varieties used in this study were all linseeds and this may account for their lack of significant variation.

Variation from Year to Year

The variation in relative rates of stem elongation and dry weight from year to year are illustrated in Figure 3 and it is shown in Tables 2 and 3 that these differences are significant. The relative rate of elongation ranged from a mean high of 0.0979 to a mean low of 0.0896 inches/day in 1950. The L.S.D. values at 1 per cent indicate that the increase in height during 1951 was significantly greater than during either 1950 or 1952; the latter two years proved non-significantly different although the growth rate of 1952 was somewhat superior to 1950. The interaction for variety by years was not significant, indicating that the varieties reacted similarly to differences in climatic conditions in the 3-year period. This was also true for the dates of seeding.

The climatic factors illustrated in Figure 3 cover the growing period up to flowering time. Significant negative relationships were found between the relative rate of elongation and maximum and minimum temperatures. Rainfall did not appear to be related to height increase, presumably because the moisture supply in each season was ample for good growth.

Effect of Date of Seeding

The relative rates of elongation and dry weight in each date of seeding are illustrated in Figure 4. A significant decline in the relative rate of elongation between the first and second seeding coincided with a significant increase in the relative rate of increase in dry weight. No such coincidence occurred between the second and third seeding. In the first seeding date dry weight growth rate was significantly less than in the other two.

It will be noted that temperatures and number of hours of sunshine were much lower in 1951 (Figure 3). Increased temperatures and sunshine showed a negative relationship with rate of stem elongation, but a positive association with the rate of dry weight increase. Similar inter-relationships were observed in the date of seeding tests (Figure 4). From this it appears

that high temperatures favour an increase in relative growth rate of dry weight, while a decrease occurs in the rate of stem elongation. Normal variations in moisture in this area did not play a great part in altering the relative growth rates.

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THE EFFECT OF LIMESTONE APPLICATIONS ON SOIL COMPOSITION, POTATO-SCAB DEVELOPMENT AND YIELDS OF POTATOES, BARLEY AND CLOVER[1]

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[Received for publication May 19, 1954]

ABSTRACT

In a field experiment begun in 1931 at Charlottetown, Prince Edward Island, ground limestone, at rates of 500, 1000, 1500, 2000 and 3000 lb. per acre, was applied periodically for a 3-year rotation of potatoes, barley and clover hay.

The analysis of soil samples, representative of the 0-6 inch depth, showed that by 1948 there was a close relationship between the rates of limestone used and the pH values, exchangeable calcium content and per cent base saturation. The analysis of subsoil samples showed that, by 1951, the effect of the limestone treatments was negligible at the 6-12 inch depth.

During the years 1940 and 1948, inclusive, there was evidence of increasing potato scab—a disease caused by *Streptomyces scabies* (Thaxter), Waksman and Henrici—particularly in plots receiving the higher rates of limestone. Consideration of crop yields for the same period showed that application of limestone had no effect on potato yields but resulted in significant increases in the case of barley and clover.

INTRODUCTION

The climate of the Maritime Provinces, which may be termed humid-temperate, has favoured the podsol type of soil development. Podsol soils are leached, relatively low in plant nutrients, and strongly acid in reaction. This latter characteristic, while desirable for the growth of potatoes in so far as control of scab—a disease caused by *Streptomyces scabies* (Thaxter), Waksman and Henrici—is concerned, is associated with unfavourable soil conditions in respect to the growth of legumes. Thus, as is frequently the case in the Maritimes, certain difficulties are encountered when potatoes and clover are grown in the same rotation.

In order to obtain information regarding the effect of limestone applications on soil composition, potato scab development, and crop yields in a 3-year rotation of potatoes, barley and clover hay, a field experiment was initiated in 1931 at the Experimental Station, Charlottetown, Prince Edward Island. Information obtained from this experiment is reported in the present paper.

MATERIALS AND PROCEDURE

The soil of the experimental area is mapped as a Charlottetown fine sandy loam (15) and, prior to the start of the experiment, had not been limed for many years. Potatoes were grown on the entire area in 1930 and no scab was found on the crop.

[1] Joint contribution from the Chemistry Division, Science Service, and Field Husbandry Division, Experimental Farms Service. Scientific Contribution No. 255, Chemistry Division.

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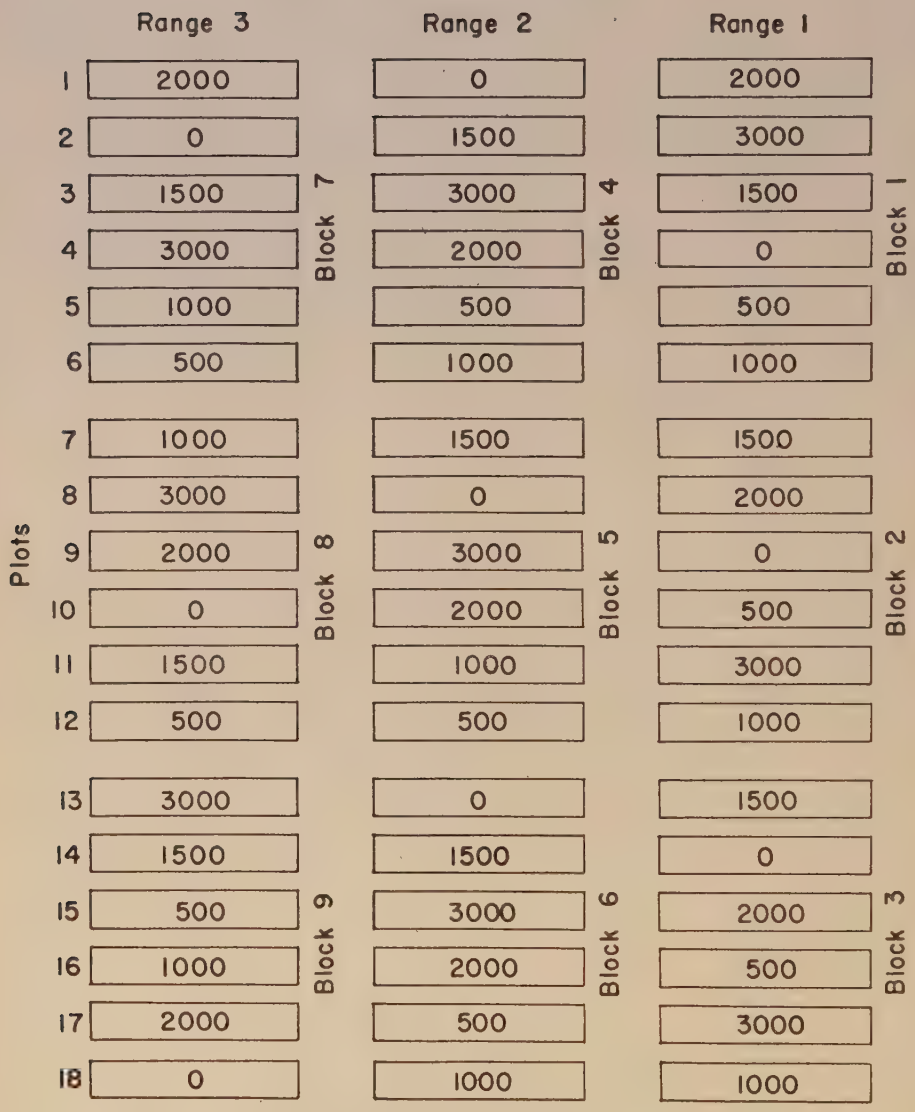

FIGURE 1. Plan of field experiment with limestone treatments in lb./A.

The plan of the experiment and the rates of limestone used are shown in Figure 1. The plots, each 13.2 feet by 55 feet (1/60th acre) were separated by 4-foot pathways. The ranges, which carried a different crop in the rotation each year, were separated by 20-foot roadways.

Prior to 1942, limestone was applied every six years. Subsequently it was applied every three years and in 1942 both the barley and clover crops received limestone. With this exception it was applied only for the barley crop. From 1931 to 1941, inclusive, a 4-8-6 fertilizer at 1200 lb. per acre was used for the potato crop. Beginning in 1942 this was changed to a 4-8-10 analysis and, in addition, 300 lb. per acre of a 2-12-10 fertilizer were applied for the barley crop.

After the experiment was laid out, and before any treatments were applied, surface and subsoil samples were taken from plots 3 and 9 in Range 1; plots 5 and 13 in Range 2; and plots 3, 9 and 16 in Range 3. In 1948 surface soil samples were obtained from each plot in the experiment. In 1951 subsoil samples, corresponding to those taken at the beginning of the experiment, were obtained. All the samples were of a composite nature. The samples of surface soil were representative of the 0-6 inch depth and the subsoil samples of the 6-12 inch depth.

When the 1948 samples were taken Range 1 had received four applications of limestone, while Ranges 2 and 3 had been limed five times. In 1951, when the subsoil samples were obtained, each of the ranges had received an additional limestone treatment.

All the soil samples were analysed for reaction (pH), total nitrogen, exchange capacity and exchangeable calcium, magnesium and potassium. With the exception of exchange capacity, the analytical methods used were those given by Wright *et al.* (16). The method described by Peech *et al.* (13), in which the adsorbed ammonia is distilled after extraction with sodium chloride solution, was used in determining base exchange capacity. The per cent base saturation was obtained by expressing the sum of the exchangeable bases as a percentage of the cation exchange capacity.

RESULTS AND DISCUSSION

Soil Composition

The average values for the chemical analyses of surface soil samples taken in 1930 and 1948 are presented in Table 1.

A comparison of the values for the seven samples taken at the start of the experiment with those for the nine samples taken from unlimed plots in 1948 shows that certain changes have occurred. The increase in soil acidity has been small as have the decreases in exchangeable calcium, base saturation and nitrogen content. The changes in respect to exchangeable magnesium and potassium have been very pronounced. In terms of the 1930 values, the decrease in exchangeable magnesium was approximately 62 per cent while the increase in exchangeable potassium approximated 69 per cent.

The values for the 1948 samples show a close relationship between the rates of limestone applied, soil reaction, exchangeable calcium and per cent base saturation. While there was an increase in exchangeable magnesium with increasing rates of limestone application, the analytical

TABLE 1.—AVERAGE VALUES OF CHEMICAL ANALYSES OF SURFACE SOILS

Year sampled	Rate of limestone application	pH[2]	Exchangeable cations[1]			Exchange capacity[1]	Base saturation	Nitrogen
			Ca	Mg	K			
	lb./acre		me	me	me	me	%	%
1930 (7)[3]	—	5.16	2.57	0.34	0.16	9.35	33.8	0.22
1948 (9)	0	4.92	2.33	0.13	0.27	9.53	26.5	0.19
1948 (9)	500	5.11	3.03	0.15	0.26	9.37	36.6	0.19
1948 (9)	1000	5.24	3.62	0.20	0.26	9.53	40.6	0.19
1948 (9)	1500	5.43	4.30	0.20	0.25	9.64	49.3	0.19
1948 (9)	2000	5.53	5.14	0.22	0.28	9.83	57.4	0.19
1948 (9)	3000	5.92	6.05	0.24	0.23	9.76	66.6	0.19

[1] In 100 gm. soil.
[2] Obtained by averaging hydrogen ion concentrations.
[3] Figures in brackets refer to the number of values averaged.

results for the individual soil samples provided an explanation. The magnesium content of the plots in Range 3 was relatively high in comparison with that of the plots in Ranges 1 and 2 receiving similar amounts of limestone. It is believed possible that, on at least one occasion, dolomitic rather than calcitic limestone was applied to Range 3. This could account for the relatively high magnesium values which, in respect to the average values in Table 1, are responsible for the relationship between exchangeable magnesium and rates of limestone application. There is no indication that the amount of limestone applied has influenced the exchange capacity, the nitrogen content or the level of exchangeable potassium. In so far as potassium is concerned, similar findings have been reported by Moschler *et al.* (10). The increase in exchangeable potassium from 1930 to 1948 may be attributed to the fertilizer potassium applied.

Bear and Toth (2) have suggested that, in an ideal soil, 65 per cent of the exchange complex should be occupied by calcium, 10 per cent by magnesium, 5 per cent by potassium and the remainder by hydrogen. They have further stated that, in acid soils used for potato production, a 2 to 1 ratio of magnesium to potassium is important in order that potassium is not taken up by the plants at the expense of the magnesium. In general, in the experiment at Charlottetown, those plots receiving the highest rate of limestone had approximately 65 per cent of their exchange complex occupied by calcium but only in Range 3 did the magnesium-to-potassium ratio approximate 2 : 1. In view of this, it would appear that the use of dolomitic limestone might be preferable in respect to the conditions of this experiment.

The results of analyses of subsoil samples, taken in 1930 and in 1951, are presented in Table 2. There is no indication that the application of limestone has resulted in any marked or consistent changes. It will be noted, however, that exchangeable magnesium has decreased in all cases as it did in the surface soil samples. Results reported by Blair and Prince (4) show that limestone applications, at rates of 1000, 2000 and 4000 lb. per acre, changed surface and subsoil reaction of a Sassafras loam to about the same degree. The limestone was applied at 5-year intervals during a 25-year period. Brown and Munsell (5), who worked with a Charlton fine sandy loam, have stated: "On this soil, at least, ten years must elapse after applying limestone at two tons on the surface before all of the upper six inches have a similar reaction". They concluded that the time since application and rate of limestone used were important factors affecting the degree and depth to which soil acidity was reduced.

Potato Scab Development

Observations regarding the occurrence and extent of potato scab from 1943 to 1948, inclusive, are presented in Table 3. While there are some inconsistencies, the application of limestone has promoted scab development. This is particularly so with respect to the higher rates of limestone used. Cook and Nugent (7) found a relationship between soil reaction and scab. They concluded that calcium compounds affect scab only to the extent that they change soil reaction. Nelson and Brady (11) have reported that, when dolomitic limestone was mixed with the surface soil,

TABLE 2.—CHEMICAL ANALYSES OF SUBSOILS

Range	Plot	Limestone applied 1931-1951	pH		Exchangeable cations*						Exchange capacity*		Base saturation	
					Ca		Mg		K					
			1930	1951	1930	1951	1930	1951	1930	1951	1930	1951	1930	1951
		lb./acre			me	me	me	me	me	me	me	me	%	%
1	9	0	5.3	5.3	2.50	1.61	0.23	0.08	0.15	0.17	7.47	6.49	38.3	28.7
2	13	0	5.5	5.3	2.95	1.71	0.13	0.10	0.12	0.14	7.74	6.62	41.6	29.5
2	5	3000	5.0	5.1	1.54	2.25	0.20	0.08	0.15	0.15	4.66	5.57	40.6	44.5
3	16	6000	4.7	5.0	1.27	1.00	0.15	0.10	0.23	0.14	6.52	4.02	25.3	31.1
1	3	7500	5.3	5.3	3.79	2.82	0.25	0.15	0.11	0.15	8.19	7.15	50.7	43.6
3	3	9000	4.9	5.1	1.43	1.93	0.20	0.15	0.17	0.14	7.68	7.79	23.4	28.6
3	9	12000	5.1	5.2	1.30	1.22	0.17	0.10	0.13	0.13	7.89	6.44	20.3	22.5

* In 100 gm. soil.

TABLE 3.—RECORDED OCCURRENCE OF POTATO SCAB

Rate of limestone application	Crop year					
	1943 (2)[1]	1944 (3)	1945 (1)	1946 (2)	1947 (3)	1948 (1)
lb./ac.						
0	None	Trace[2]	None	None	None	Trace
	None	None	None	Trace	Trace	Trace
	None	None	None	None	None	Trace
500	None	None	None	2%	Trace	Trace
	None	None	None	Trace	Trace	Trace
	None	Trace	None	10%[3]	Trace	10%
1000	None	None	None	Trace	Trace	Trace
	None	None	None	Trace	Trace	Trace
	Trace	Trace	None	3%	None	None
1500	None	None	None	Trace	10%	Trace
	None	Trace	None	Trace	10%	Trace
	None	None	None	Trace	10%	Trace
2000	None	Trace	None	10%	Trace	90%
	None	None	None	Trace	Trace	Trace
	Trace	Trace	None	10%	None	10%
3000	Trace	Trace	None	10%	Trace	Trace
	Trace	None	1%	Trace	20%	100%
	None	None	Trace	15%	30%	100%

[1] Figures in brackets are the range numbers.
[2] Trace = 1 scab spot per tuber on several tubers per plot.
[3] 10% = approximately 10% of tubers carry scab spots.

scab infection was increased. In discussing soil reaction and calcium supply in relation to yield and occurrence of scab, Odland and Allbritten (12) have stated that a pH value of 5.0 to 5.5 was recommended for best yield and least scab.

Crop Yields

It was considered that by 1940 soil differences, other than those resulting from the application of limestone, would tend to have levelled off and the effect of the limestone treatments on yields could be better evaluated. In view of this, as well as the fact that surface soil samples were taken from all plots in 1948, it was thought that the yields obtained from 1940 to 1948, inclusive, would best reflect the influence of liming. During this period each crop occurred three times on each range. An analysis of variance of the crop yields is presented in Table 4.

With reference to the yields of potatoes, the results show the differences between ranges and between years within ranges to be highly significant. The fact that relatively low yields were obtained in 1941, 1943 and 1945 may be partially responsible for this. In 1941 and 1943 there was an excess of moisture, while in 1945 the rainfall during July and August was approximately half the usual amount. Table 4 shows that the limestone treatments had no significant effect on yield. While Carolus (6) found

TABLE 4.—ANALYSIS OF VARIANCE OF THE CROP YIELDS

Source of variation	Degrees of freedom	Mean square		
		Potatoes	Barley	Clover
Ranges	2	149900.4**	399.7**	9.6**
Years within ranges	6	141261.0**	1258.4**	6.2**
Treatments within ranges	15	349.3	76.3	0.8
Treatments	5	53.2	195.2**	2.2**
Lime vs. no lime	1	6.0	639.3**	5.8**
Rates of lime	4	65.0	84.2	1.3
Treatments × ranges	10	498.3	16.8	0.1
Replications within ranges	6	475.5	227.6**	0.6
Years within ranges × treatments within ranges	30	465.0	19.2	0.9
Years within ranges × replications within ranges	12	782.6[1]	63.8[1]	0.2[1]
Treatments within ranges × replications within ranges	30	288.4[2]	50.8[2]	0.5[2]
Years within ranges × treatments within ranges × replications within ranges	60	340.9[3]	21.0[3]	0.5[3]

[1] Error mean square for years within ranges.
[2] Error mean square for ranges and treatments within ranges.
[3] Error mean square for replications within ranges.

that calcium did not seem to be an important factor in the growth and yield of potatoes, Berger (3) has reported yield increases from the use of dolomitic limestone. Hawkins, Chucka and Brown (8) have also reported beneficial results from light applications of dolomitic limestone when a deficiency of magnesium caused reduced yields. Odland and Allbritten (12) have reported yields were not affected by pH in the range 4.6 to 6.1.

With barley, there was a significant effect from the application of limestone. Both Ahlgren (1) and Klages (9) have pointed out that barley is sensitive to soil acidity.

The recorded clover yields represented the weight of all plant growth on each plot. Field notes, taken during the growing season, showed that considerable and rather consistent differences existed among the plots each year with respect to the per cent of clover present. In the plots receiving no limestone, clover seldom accounted for more than 10 per cent of all growth with the remainder being volunteer red top, daisies and other weeds. In the plots receiving the highest rate of limestone, clover represented at least 75 per cent of all growth. Thus the limestone treatments had more influence on this crop than was indicated by the recorded yields. The analysis of variance of the clover yield data, presented in Table 4, shows the differences between treatments to be highly significant. According to Ahlgren (1) a pH range of 6.0 to 6.5 is satisfactory for the growth of clover. Snider (14), commenting on the growth of this crop, has pointed out that adequate amounts of phosphorus and potassium as well as lime are necessary for satisfactory growth.

The average yields for all crops are presented in Table 5. There is an indication that the yields of barley and clover tended to level off with the higher rates of liming.

TABLE 5.—AVERAGE YIELDS OF POTATOES, BARLEY AND CLOVER FROM 1940 TO 1948, INCLUSIVE

Crop	Rate of limestone application lb./acre					
	0	500	1000	1500	2000	3000
Potatoes (bu./A)	191	191	191	192	194	190
Barley (bu./A)	28.2	31.0	33.0	34.9	33.2	35.5
Clover (tons/A)	0.873	1.032	1.356	1.425	1.473	1.611

L.S.D. (P 0.05), for barley = 3.96.
L.S.D. (P 0.05), for clover = 0.395.

ACKNOWLEDGMENTS

The field work was carried out under the supervision of D. C. Schurman, formerly Senior Agronomist, Experimental Station, Charlottetown. Mr. Schurman's assistance is gratefully acknowledged. The authors also wish to express appreciation to G. B. Oakland, Head, Biometric Unit, Science Service, and to John Friesen, Chemistry Division, Science Service, for assistance with the statistical treatment of data.

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SAWFLY RESISTANCE IN WHEAT. I. TYPES OF RESISTANCE[1]

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[Received for publication May 12, 1954]

ABSTRACT

The sawfly resistance of seven varieties of wheat has been examined. The varieties have been found to differ in (1) infestability, (2) resistance to the development of eggs and establishment of first-instar larvae, and (3) resistance to development of older larvae. Environmental factors affect these three different types of resistance in different ways. Stem solidness is not a thoroughly reliable measure of sawfly resistance and should not be used as such if it is possible to make tests with live sawflies.

INTRODUCTION

The wheat stem sawfly, *Cephus cinctus* Nort., is a serious pest over a large part of the drier regions of the Canadian prairies. Its life cycle has been known for some time (1). The adult sawflies emerge from the wheat stubs in late June and early July when the wheat is in the shot-blade or boot stage. The eggs are laid in the stems at this time. The larvae tunnel inside the stems until the wheat is almost ripe. At this time they work their way down to the base of the stem and cut a groove around the inside of the stem just above the ground level. The stems break off at this groove and fall to the ground. The chief economic loss is caused by the difficulty of harvesting the cut stems. However, the tunnelling of the larvae also causes a reduction in yield (9). The larvae plug the stem with frass just below the groove they cut and overwinter in the basal part of the wheat stem or stub. The adults emerge in time to lay the eggs in the following wheat crop and the cycle is repeated.

Early work (3, 4) on this pest suggested that solid-stemmed wheats were resistant to damage by sawflies because the larvae were unable to chew through the pith and nodal plates within the stem. Consequently a solid-stemmed sawfly-resistant variety of wheat known as Rescue was developed. However, it was soon discovered that, under some conditions which prevailed frequently around Regina (8), the sawfly resistance of this variety broke down. Rather serious breakdowns in the sawfly resistance of this variety have also been noted in nursery plots in Montana (8), and also in the Lethbridge region in 1951 and 1953. For this reason additional detailed studies of the nature of sawfly resistance and the effects of environment on this resistance were undertaken.

A preliminary field test, made in 1950, indicated that there might be differences between the varieties of wheat in (1) percentage infestation by sawflies, (2) percentage of infested stems in which eggs hatched and larvae started feeding, (3) percentage of stems where larvae that survived the first day or two would survive to the stage at which they cut the stems, and (4) vigour of the larvae cutting the stems. This paper deals with data obtained during a 3-year study of these differences.

[1] Contribution No. 1389 from the Botany and Plant Pathology Division, Science Service, Department of Agriculture, Ottawa.

[2] Plant Physiologist.

MATERIALS AND METHODS

Seven varieties of wheat were used for these experiments for the reasons indicated. Thatcher was a typical hollow-stemmed susceptible type. Red Bobs was thought to possess more resistance than Thatcher although it also was hollow-stemmed. Rescue, a solid-stemmed wheat, is grown commercially and its breakdown in resistance was one of the chief reasons for this work. Golden Ball, a durum wheat, was the most solid stemmed and also the most resistant wheat available. Melanopus, a durum wheat, was selected since it approaches Golden Ball in resistance and yet is not solid-stemmed (7). Two hybrids were also used. H46146 had proved to be relatively resistant to sawfly attacks in the Regina area. H4191 was chosen since most of the sawflies emerging from stubs of this variety are males* (10).

The wheat varieties were seeded on dry land in 8-foot rows, spaced 1 foot apart. The rows of the 7 varieties were randomized in each replicate. In 1950 the plot was adjacent to an area with a severe natural infestation. In the two subsequent years artificial infestation was used. This was achieved by transplanting stubs from an infested area to the spaces between the rows of wheat in the test plots. Eighty stubs were used for each test row. After the wheat varieties had matured under the type of sawfly infestation described above the plants were dug up and examined in the laboratory.

The number of stubs in each plot was counted. The stems that were not cut by sawflies were split with a razor blade and classified into 3 groups on the basis of (1) infestability, determined as the percentage of stems infested; (2) survival of eggs and first-instar larvae in infested stems; and (3) survival of older larvae. Stems in which there was no trace of sawfly activity were classified as "not infested". There is the possibility that some of these stems had been infested but that all traces of the eggs had disappeared. This is unlikely, except in the hollow-stemmed varieties, Thatcher, Red Bobs, and Melanopus. Small dark or discoloured areas in other stems were interpreted as places where eggs had been laid but had not hatched. As far as possible, care was taken to distinguish between

* Farstad, C. W. *Unpublished data.*

TABLE 1.—INFESTABILITY OF WHEAT VARIETIES BY SAWFLIES IN 1950

Variety	Percentage of stems infested				Transformed value average[1]
	Replicate			Average	
	1	2	3		
Thatcher	71	71	70	71	57
Red Bobs	77	81	73	77	61
Rescue	59	60	54	58	49
H4191	41	50	40	44	41
H46146	37	30	54	40	39
Melanopus	56	67	63	62	52
Golden Ball	83	81	88	84	67

[1] Least significant difference = 17 (5 per cent level)

TABLE 2.—INFESTABILITY OF WHEAT VARIETIES BY SAWFLIES IN 1951

Variety	Percentage of stems infested												Average	Transformed value average[1]
	Replicate													
	1	2	3	5	5	6	7	8	9	10	11	12		
Thatcher	71	66	85	74	66	80	85	79	81	86	87	88	79	63
Red Bobs	68	83	—	77	84	74	73	88	85	83	85	86	81	64
Rescue	54	56	58	72	59	77	68	69	60	79	78	77	67	60
H4191	40	52	58	58	38	59	63	60	66	58	60	75	57	49.5
H46146	48	51	65	56	54	63	64	65	52	57	59	67	59	50
Melanopus	23	39	37	34	33	42	25	38	30	47	47	37	36	37
Golden Ball	18	37	37	32	21	46	41	36	32	41	23	38	34	35

[1] Least significant difference = 3.5 (5 per cent level)

TABLE 3.—INFESTABILITY OF WHEAT VARIETIES BY SAWFLIES IN 1952

Variety	Percentage of stems infested										Average	Transformed value average[1]
	Replicate											
	1	2	3	4	5	6	7	8	9	10		
Thatcher	68	80	68	47	60	71	70	76	79	75	69	57
Red Bobs	72	85	73	58	68	64	75	72	70	74	71	58
Rescue	33	39	43	42	54	42	40	35	40	43	41	40
H4191	28	30	24	41	46	30	31	38	43	30	34	36
H46146	32	46	30	49	49	37	55	36	28	40	40	39
Melanopus	40	49	49	43	42	38	37	50	41	26	42	40
Golden Ball	45	34	58	43	50	50	48	42	42	43	45	42

[1] Least significant difference = 5 (5 per cent level)

discoloured areas probably due to sawfly activity and those caused by micro-organisms alone. Some of these sawfly oviposition scars may represent places where the sawfly had inserted her ovipositor but had failed to lay an egg. Other scars may represent places where eggs were laid and hatched, but where the larva died after little or no feeding. Since there is doubt about the interpretation of these oviposition scars, the problem of the failure of sawfly eggs to hatch in some wheat varieties will have to be re-investigated by splitting wheat stems shortly after oviposition has occurred. However, the finding that there are differences between varieties in the percentage of stems with eggs not hatching, as determined from the oviposition scars found, indicates resistance to the development of the early stages of the sawflies inside the wheat stem. In other infested stems sawfly larvae had tunnelled but had failed to develop far enough to cut the stems. In the following data no records of mortality due to parasitism of these older larvae by *Bracon* sp. or *Pleurotropus* sp. were kept, although recent data of Holmes and Peterson* indicate that parasitism by *Bracon* sp. depends on the variety in which the sawfly larva is growing. Observations, made during stem splitting, however, indicate that parasitism did not cause any serious discrepancy in the data.

Since stem solidness is considered to be an important factor in sawfly resistance, 12 mature stems from each row of wheat were rated for this character by Larson's method**.

Percentage values obtained in these experiments were subjected to the inverse sine transformation before the analysis of variance was made. The least significant differences given in the tables are the value for the 5 per cent level.

RESULTS

Infestability

Highly significant differences (1 per cent level) between varieties in sawfly infestability occurred in each of the three years of tests (Tables 1, 2, and 3). Differences between replicates were not significant except in

* Holmes, N. D., and L. K. Peterson. *Unpublished data.* 1952.

** Larson, R. I. Aneuploid analysis of the inheritance of stem solidness in common wheat. *Unpublished Ph.D. thesis, University of Missouri.* 1952.

TABLE 4.—MORTALITY OF SAWFLY EGGS AND YOUNG FIRST INSTAR LARVAE IN STEMS OF WHEAT VARIETIES IN 1950

Variety	Percentage stems showing mortality of eggs and young larvae				Transformed value average[1]
	Replicate			Average	
	1	2	3		
Thatcher	6	10	9	8	16
Red Bobs	2	5	5	4	11
Rescue	35	46	39	40	39
H4191	27	38	47	37	37
H46146	72	52	43	56	48
Melanopus	39	32	33	35	36
Golden Ball	19	21	14	18	25

[1] Least significant difference = 17 (5 per cent level)

TABLE 5.—MORTALITY OF SAWFLY EGGS AND YOUNG FIRST INSTAR LARVAE IN STEMS OF WHEAT VARIETIES IN 1951

Variety	Percentage stems showing mortality of eggs and young larvae												Average	Transformed value average[1]
	Replicate													
	1	2	3	4	5	6	7	8	9	10	11	12		
Thatcher	0	1	1	2	1	1	0	1	0	0	0	0	1	3.3
Red Bobs	0	0	—	1	0	1	1	1	0	0	0	0	0.4	2.5
Rescue	17	22	8	20	34	13	19	19	11	7	18	19	17	24
H4191	21	11	19	12	36	23	18	29	11	8	27	14	19	25
H46146	28	17	20	35	17	26	27	31	33	21	26	28	26	30
Melanopus	28	16	26	24	23	30	58	24	28	23	28	16	29	31
Golden Ball	45	31	37	29	48	28	39	52	34	48	36	45	39	39

[1] Least significant difference = 4.3 (5 per cent level)

TABLE 6.—MORTALITY OF SAWFLY EGGS AND YOUNG FIRST INSTAR LARVAE IN STEMS OF WHEAT VARIETIES IN 1952

Variety	Percentage stems showing mortality of eggs and young larvae										Average	Transformed value average[1]
	Replicate											
	1	2	3	4	5	6	7	8	9	10		
Thatcher	1	2	0	0	2	2	2	2	2	0	1.3	5.4
Red Bobs	1	0	0	1	2	3	1	1	1	0	1.0	4.8
Rescue	29	43	53	52	30	48	13	19	29	32	35	36
H4191	16	54	62	46	29	33	37	29	41	35	38	38
H46146	58	47	29	42	50	29	50	33	10	23	37	37
Melanopus	37	31	19	39	29	26	29	11	24	20	27	31
Golden Ball	23	32	25	12	29	27	18	19	18	9	21	27

[1] Least significant difference = 7

1951 when they exceeded the 1 per cent level. An interaction between years and varieties, significant at the 1 per cent level, was found for 1951 and 1952.

The vulgare wheats usually ranked in order of decreasing infestability for each of the three years as follows: Red Bobs, Thatcher, Rescue, H46146, and H4191. The rank of the two durum wheats (Melanopus and Golden Ball) changed each year in relation to the vulgare wheats. It appears as if growing conditions influence the infestability of these durum wheats. Only in 1951 were significant differences between replicates found in these tests. This suggests that soil heterogeneity may modify the infestability. One cannot, however, compare directly the percentages of stems infested in the different years because the sawfly populations differed numerically in each case.

The present experiments confirm the findings of Kemp (4), and Platt and Farstad (7) that there are differences between the varieties in infestability.

Mortality of Eggs and Young Larvae

The data on egg mortality for the three years' tests (Tables 4, 5, and 6) show that there are highly significant differences (1 per cent level) between varieties in the percentage of infested stems within which eggs hatch. The differences between replicates were not significant. The interaction between years and varieties for 1951 and 1952 was significant at the 1 per cent level.

The order of the vulgare wheats was consistent from year to year. The data of Wall* on Thatcher, Red Bobs, Rescue, and Golden Ball agree with those presented above. The durum wheats occupied the same positions in the list of varieties in 1950 and 1952 but not in 1951. The summer of 1951 was an unusual season with much cold, cloudy weather in the month of June. Platt (6) has shown that there is a breakdown in stem solidness, and supposedly in sawfly resistance, in those years having a small number of hours of June sunshine [June 1950—253 hours, June 1951—240 hours, June 1952—289 hours, average—276 hours (5)]. It will

* Wall, A. M. *Unpublished data.*

TABLE 7.—SURVIVAL OF OLDER SAWFLY LARVAE IN STEMS OF WHEAT VARIETIES IN 1950

Variety	Percentage of larvae-containing stems that were cut				Transformed value average[1]
	Replicate			Average	
	1	2	3		
Thatcher	81	76	84	80	64
Red Bobs	86	78	85	83	66
Rescue	46	40	37	41	40
H4191	60	65	82	69	57
H46146	78	61	64	68	55
Melanopus	66	78	68	71	57
Golden Ball	64	54	68	62	52

[1] Least significant difference for transformed averages = 18

TABLE 8.—SURVIVAL OF OLDER SAWFLY LARVAE IN STEMS OF WHEAT VARIETIES IN 1951

Variety	Percentage of larvae-containing stems that were cut												Average	Transformed value average[1]
	Replicate[2]													
	1	2	3	4	5	6	7	8	9	10	11	12		
Thatcher	96	80	78	68	95	89	91	92	77	81	92	85	85	68
Red Bobs	81	78	—	82	87	88	91	90	76	84	89	87	85	67
Rescue	77	77	67	88	86	91	82	81	69	81	79	87	80	64
H4191	82	69	70	77	84	89	88	89	74	81	86	91	82	65
H46146	72	71	79	76	80	87	86	68	73	73	94	98	80	64
Melanopus	38	56	78	75	75	64	76	58	57	58	38	64	62	52
Golden Ball	88	75	65	71	65	73	68	92	60	74	82	60	73	59

[1] Least significant difference for transformed averages is 6.3
[2] Replicates 1–4 and 9–10 in range 1, 5–8 and 11–12 in range 2

be noted that the egg mortality in the vulgare wheats was low in 1951 compared with the other years. This was not true for Melanopus whereas Golden Ball showed increased egg mortality in 1951. It is possible that light duration and intensity are two of the factors influencing egg mortality in the tested varieties of wheat and that the resistant vulgare wheats are more sensitive to these factors than the durum wheats.

Larval Survival

The data on the percentages of larva-containing stems that were cut are given in Tables 7, 8, and 9. Differences between varieties were significant at the 1 per cent level in all three years. It is interesting to note that differences between replicates were significant at the 5 per cent level in 1951 and at the 1 per cent level in 1952. These differences suggest that soil conditions, probably mineral nutrition of the plants, affect the survival of hatched sawfly larvae within the host plant stems. In both 1951 and 1952 the test rows were laid out in two adjacent ranges in the field (Tables 8 and 9). When the data from each range were analysed separately the differences between the replicates disappeared completely in 1951 and largely in 1952. There was no significant interaction between ranges and varieties in either year. An interaction significant at the 1 per cent level was found between years and varieties for 1951 and 1952.

An examination of the data shows clearly that there are differences between the varieties in larval survival. Thatcher and Red Bobs are consistently good hosts. The other vulgare wheats are more variable in their reaction. Rescue showed resistance to larval development in 1950 and 1952 but not in 1951. H46146 showed resistance in 1952 only. Apparently, environmental factors influence the resistance of the vulgare wheats to larval development. Larval survival in the vulgare wheats in 1951, when June was wet and cloudy, was better than in the other two years. This corroborates the breakdown of sawfly resistance in a year with little June sunshine (6). Among the durums Melanopus was significantly more resistant to larval development than Golden Ball in 1951 and 1952 while there was no significant difference between the varieties in 1950. There was a difference between the durums and the vulgare wheats in their reaction to the soil heterogeneity in 1951 and 1952. In 1952 the reaction of the two species of wheat was similar in both ranges of plots. However, in 1951 the resistance of the vulgare wheats was lower in one range than the other, whereas the durums behaved the same way in both ranges.

The percentage of stubs of the different varieties from which sawflies emerged was noted. When these data were analysed it was found that there was no significant difference between the varieties in 1951 or 1952. The varieties did show differences in 1950 when there were only 3 replicates. It cannot be safely concluded from these data that there are not differences when the stubs over-winter in the field.

Stem Solidness

The data on stem solidness are presented in Tables 10, 11, and 12. Differences between varieties were significant at the 1 per cent level in all three years. In 1952 the differences between replicates were significant at the 1 per cent level, whereas in the other two years they were not significant.

TABLE 9.—SURVIVAL OF OLDER SAWFLY LARVAE IN STEMS OF WHEAT VARIETIES IN 1952

Variety	Percentage of larvae-containing stems that were cut										Average	Transformed value average[1]
	Replicate[2]											
	1	2	3	4	5	6	7	8	9	10		
Thatcher	68	67	66	69	66	78	81	83	90	82	75	60
Red Bobs	53	46	71	61	53	70	79	73	84	87	68	56
Rescue	51	48	50	43	42	56	61	68	55	40	51	46
H4191	68	35	69	72	51	48	74	82	69	58	63	53
H46146	23	44	39	45	28	53	52	52	53	54	44	42
Melanopus	46	40	60	47	62	46	57	75	75	43	55	48
Golden Ball	54	81	62	61	54	71	76	72	61	56	65	54

[1] Least significant difference for transformed averages is 5.7 (5 per cent level)
[2] Replicates 1–5 in range 1, 6–10 in range 2

TABLE 10.—STEM SOLIDNESS OF WHEAT VARIETIES IN 1950

Variety	Solidness rating			Average[1]
	Replicate			
	1	2	3	
Thatcher	8	8	9	8
Red Bobs	7	8	7	7
Rescue	22	28	31	27
H4191	26	31	28	28
H46146	32	29	31	31
Melanopus	22	23	25	23
Golden Ball	35	35	35	35

[1] Least significant difference = 7 (5 per cent level)

Stem solidness has frequently been used as a method of determining sawfly resistance. Solid stemmed wheats are considered to be resistant. In the case of the durum wheats, Eckroth and McNeal (2) did not find a close association between stem solidness and sawfly resistance.

When the data for infestability (Tables 1, 2, and 3) and for stem solidness are compared the varieties occur in the same order with a few noteworthy exceptions. In 1950, Golden Ball, the most solid-stemmed variety, was the most infestable. In 1951 Melanopus was less infestable than the resistant vulgare wheats although it was less solid-stemmed.

Sawfly eggs hatch well in the two very hollow-stemmed varieties, Thatcher and Red Bobs. The association of stem solidness with the mortality of eggs and early larval stages (Tables 4, 5, and 6) is not very good among the solid-stemmed and partially solid-stemmed varieties. In 1950 and 1952 the egg-hatch was better in Golden Ball than in any of the other four solid-stemmed varieties although Golden Ball was the most solid-stemmed variety in these two years. Although Melanopus is more hollow-stemmed than the resistant vulgare wheats tested, in 1951 the egg and early larval mortality in this variety was greater than it was in two of the three solid-stemmed vulgare wheats. The three resistant vulgare wheats were all more favourable hosts for sawfly egg development in 1951 than in the other years, and they also tended to be more hollow-stemmed. This statement is not true for the two durum wheats.

When the data on the survival of the older larvae (Tables 7, 8, and 9) are compared with the data on stem solidness, little justification can be found for attempting to associate these two phenomena. In 1950 the larval survival was outstandingly poor in Rescue, yet this variety did not have an especially solid stem. In 1951 there was little difference between the vulgare wheats in resistance to larval survival but there were big differences in stem solidness. In the durums, the more solid-stemmed variety had the better larval survival. In the 1952 data there was poor agreement between stem solidness and resistance to larval development. There was no significant difference in larval survival between the most hollow-stemmed variety, Red Bobs, and the most solid-stemmed variety, Golden Ball (Table 9). Melanopus, a partially hollow-stemmed variety, and the solid-stemmed Rescue and H46146 were all significantly more

TABLE 11.—STEM SOLIDNESS OF WHEAT VARIETIES IN 1951

	Solidness rating												
	Replicate												Average[1]
	1	2	3	4	5	6	7	8	9	10	11	12	
Thatcher	10	11	11	7	9	9	11	11	9	11	10	9	10
Red Bobs	8	10	8	10	8	8	8	8	8	8	9	8	8
Rescue	22	24	23	28	27	24	26	28	26	27	28	25	26
H4191	27	31	23	24	32	26	29	27	22	25	26	26	27
H46146	29	30	28	28	28	30	29	29	26	25	29	29	28
Melanopus	22	24	20	20	21	—	31	22	20	25	17	24	22
Golden Ball	34	33	34	34	35	34	35	34	34	34	33	34	34

[1] Least significant difference = 1.8 (5 per cent level)

TABLE 12.—STEM SOLIDNESS OF WHEAT VARIETIES IN 1952

Variety	Solidness rating										Average[1]
	Replicate										
	1	2.	3	4	5	6	7	8	9	10	
Thatcher	9	9	12	11	11	8	9	9	9	10	10
Red Bobs	9	7	7	8	7	8	8	8	9	9	8
Rescue	31	32	32	29	32	32	31	29	31	32	31
H4191	29	31	32	29	29	28	29	28	31	29	29
H46146	34	32	34	31	31	32	30	32	31	30	32
Melanopus	27	32	22	21	21	25	22	22	24	23	24
Golden Ball	34	34	35	35	34	35	35	35	34	34	34

[1] Least significant difference = 1 (5 per cent level)

resistant to larval development than either Red Bobs or Golden Ball. Differences in stem solidness corresponding to differences in larval survival between the two ranges of plots in 1951 and 1952 were not found.

The data show that stem solidness cannot be used as a reliable measure of over-all sawfly resistance among the durum or vulgare wheats. The association of stem solidness with resistance is poor in the two durum wheats and in the group of seven wheats as a whole. Among the vulgare wheats, stem solidness appears to be associated with infestability and with mortality of the eggs and early larvae. There is little evidence for the association of stem solidness and mortality of the older larvae in the vulgare wheats. In considering these data it must be remembered that the resistant vulgare wheats, Rescue, H4191, and H46146, all derive their sawfly resistance from S-615. One may expect that their reactions will be similar. This may explain the apparent association, under dry-land conditions, of stem solidness and sawfly resistance among the vulgare wheats. The results indicate that it is not safe to use stem solidness as a measure of sawfly resistance when dealing with varieties having an unknown sawfly reaction.

DISCUSSION

The data presented indicate significant differences in sawfly reaction between wheat varieties in (1) infestability; (2) survival of the eggs from the time of laying up to the feeding stage; and (3) survival of the feeding larvae up to the time of cutting. The soil conditions under which the host plant was grown influenced larval survival within the host but these conditions did not influence egg hatchability. The order of the varieties for larval survival is different from the order for either infestability or egg hatchability and is quite variable from year to year. It is likely that the genetic factors in the wheat responsible for egg hatchability are at least partly different from those responsible for the survival of the older larvae. A similar situation exists between infestability and egg hatchability suggesting that these two factors are partly determined by different gene loci.

Since it is apparent that sawfly resistance may be divided into at least three phases, it is unlikely that a single morphological character such as stem solidness can give an accurate measure of sawfly resistance. This does not rule out the possibility that stem solidness or some result of stem solidness may be a factor in sawfly resistance but it does mean that other important factors are also involved.

ACKNOWLEDGMENTS

The author is indebted to A. W. Platt, formerly Officer-in-Charge, M. N. Grant, Officer-in-Charge, and J. B. Dore, all of the Cereal Breeding Laboratory, Experimental Station, Lethbridge, for supplying the seed and for assistance with the plot work; and to C. W. Farstad and his staff of the Field Crop Insect Laboratory at Lethbridge who gave valuable advice regarding the methods used to assess sawfly reaction.

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ZINC FOR POTATOES IN NOVA SCOTIA[1]

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[Received for publication May 26, 1954]

ABSTRACT

In an experiment at Kentville, Nova Scotia, to study the effect of zinc salts on yield and quality of potatoes, zinc treatments were applied: (*a*) by soaking tubers and sets in a solution of zinc sulphate prior to planting; (*b*) as a spray to the growing plants; (*c*) in solution to the soil immediately before planting. The zinc content of the tubers varied from 16 to 59 p.p.m. Zn in the first year of the experiment and from 9 to 32 p.p.m. Zn in the second year. With one exception, the values for zinc in petioles where no zinc spray was applied ranged from 12 to 21 p.p.m. Zn. The zinc content of 40 soil samples from plots where zinc was not applied as a spray or in solution ranged from 33 to 55 p.p.m. Zn. The treatments had no significant effect on yields in either year. One spray treatment and zinc applied in solution to the soil significantly increased the total zinc content of the soil.

Although the use of zinc in the nutrition of plants was recorded in the literature about 50 years ago, widespread interest did not develop until the publication in 1926 of the work of Sommer and Lipman (4) on the indispensable nature of zinc for higher plants. Ellis (1) and Hoyman (2) reported increases in potato yields from the use of zinc in sprays but obtained no response to soil applications containing zinc. Morgan (3) found no apparent beneficial effect on potatoes from including zinc in fertilizer. Terman and Hawkins (5), on the other hand, did obtain some yield increases from the use of zinc sulphate.

In 1952, an experiment was begun at Kentville, N.S., to study the effect of zinc salts on yield and quality of potatoes. Plots 13 feet by 16 feet, separated by pathways of 5 feet, were laid out on a sandy loam soil, moderately acid (pH 5.8) and containing 5.0 per cent organic matter. Four of the seven treatments used involved soaking the tubers or sets in zinc sulphate solution prior to planting; two treatments involved spraying the foliage with a solution containing zinc sulphate; and one consisted of applying the zinc salt in solution to the soil immediately before planting the sets. (*For details, see Table 2*). These treatments, and one check treatment, were randomized within each of four blocks. The experiment was conducted during two successive years. The Keswick variety of potato was grown. All plots received a basic dressing of 6-12-6 fertilizer at the rate of 2000 lb. per acre. During the season, all plots received an eradicant pesticide spray consisting of 2 lb. 50 per cent W.P. DDT per gal. water, applied so as to wet the plants thoroughly.

Records of the yield from each plot were kept. Samples of the tubers were analysed for specific gravity, total solids, zinc content, and ash. The starch content was calculated from the specific gravity value. In the second year, in addition to the foregoing analyses, samples of leaf petioles were analysed for zinc. Soil samples, composites of eight sub-samples per plot, were taken in the fall of each year to study the effect of treatment and were analysed for reaction (pH), nitrate-nitrogen, total phosphorus, available (Truog) phosphorus, organic matter, total zinc, and the exchangeable cations calcium, magnesium, potassium and manganese.

[1] Contribution No. 257, Chemistry Division, Science Service.

TABLE 1.—COMPOSITION OF POTATO TUBERS

Determinations	First year			Second year		
	Min.	Max.	Mean	Min.	Max.	Mean
Sp. Gr.	1.083	1.092	1.087	1.074	1.087	1.080
% Starch (Sp. Gr.)	15.37	17.41	16.26	14.69	16.38	15.47
% D.M. (Sp. Gr.)	19.46	21.95	20.58	18.54	20.73	19.58
% D.M. (Vac. ov.)	19.43	24.71	21.99	17.81	22.57	20.14
% Ash	2.79	4.34	3.74	—	—	—
p.p.m. Zn.	16	59	30	9	32	19

TABLE 2.—ZINC CONTENT OF PETIOLES AND OF SOIL SAMPLES

Treatments	p.p.m. Zn in petioles (range in 4 rep.)	p.p.m. Zn in soil (range in 8 samples)
(*a*) Whole tubers soaked 1½ min. in 1% $ZnSO_4 . 7H_2O$ solution, let dry, cut to sets, planted	12–16	38–53
(*b*) Same as (*a*), soaked 3 min.	13–44	36–45
(*c*) Sets treated as in (*a*) for 1 min., let dry at room temp., planted	14–16	33–55
(*d*) Same as (*c*) but held at room temp. two days before planting	15–21	38–47
(*e*) Parzate[1] (2 qt./100 gal.) + $ZnSO_4 . H_2O$ (1 lb./100 gal.) applied as spray 5-6 times per season	884–2064	39–55
(*f*) Dee-cop[2] (6 lb./100 gal.) + $ZnSO_4 . H_2O$ (1 lb./100 gal.) applied as spray 5-6 times per season	1174–1461	45–62
(*g*) $ZnSO_4 . 7H_2O$ (30 lb./ac.) applied to soil in water solution and mixed to 3″-4″ depth	13–19	41–57
(*h*) Check—no treatment	14–15	34–49

[1] A carbamate fungicide.
[2] 15 per cent DDT–30 per cent copper.

A summary of the information obtained on analysis of the potato tubers is given in Table 1. Specific gravity was determined by means of a potato hydrometer. The results were checked against those obtained by weighing individual tubers in air and in water, and by comparing individual tubers to saline solutions of known specific gravity, in order to obtain a correction factor for the hydrometer used. Starch and dry matter content were calculated from the specific gravity, and dry matter was also determined by drying samples in a vacuum oven for 16 hours at 70° C. Ash was determined by ignition at 500-550° C. after preliminary drying in a

dehydrator at 60° C. Zinc was determined in the ash by the dithizone method. A statistical examination of the results showed that the treatments had no significant effect either on yield or on any of the values determined in either year.

In the second year of the experiment, samples of petioles collected at random from each plot were analysed for zinc. The results, together with the treatments, are presented in Table 2. The values in the petioles collected from plots where no zinc spray had been applied ranged from 12 to 21 p.p.m. Zn, with the exception of one sample which contained 44 p.p.m. The mean value was 17 p.p.m. Zn. Where zinc had been applied as a foliage spray, the values for the petioles were very much greater.

The zinc content of 40 soil samples taken in the fall of 1952 and 1953 are summarized in Table 2. Where no zinc was applied either in solution or as a spray, the soil Zn values ranged from 33-55 p.p.m., the average value being 43 p.p.m. Zn. Significant increases in the zinc content of the soil were obtained each year from treatments *f* and *g*. Otherwise, the treatments had no significant effect on any of the determinations made.

The total zinc content of 14 samples of soil from various parts of Nova Scotia was determined. The samples represented the surface six inches of soils of varying textures, some of which had been limed and fertilized. The results obtained ranged from 23 to 86 p.p.m. Zn.

ACKNOWLEDGMENT

The authors gratefully acknowledge the co-operation of the Experimental Farms Service and the Plant Protection Division in carrying out the study, and the generous assistance of H. J. Atkinson in the preparation of the manuscript.

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THE EFFECT OF FEEDING SWEET CLOVER SILAGE ON THE PROTHROMBIN TIME OF BLOOD OF CATTLE[1]

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[Received for publication April 29, 1954]

ABSTRACT

Significantly higher prothrombin times were found in two herds of cattle being fed sweet clover silage. In one herd on similar roughage prothrombin time was normal. In one affected herd silage of a non-mouldy, dark-brown quality was fed almost entirely for 10 to 14 days before the study. In the other affected herd the daily ration consisted of about 25 per cent of dark-brown silage and 75 per cent of good quality silage. In the unaffected herd the dark-brown silage was fed about once a week and good quality silage the remainder of the time. It is considered that an anti-coagulant developed in the mouldy and dark-brown sweet clover silage. The anti-coagulant is assumed to be dicumarol.

INTRODUCTION

Sweet clover is used extensively in northeastern Saskatchewan for forage and for soil improvement. It is one of the highest yielding forage crops but weather conditions in the above region are such that curing of hay is often very difficult. Mainly in an effort to circumvent the curing problem a few farmers preserved sweet clover as silage in 1953.

It is well known that the feeding of sweet clover hay which has spoiled during the curing process may result in hemorrhagic sweet clover disease (1, 2, 5, 6, 7, 8, 10). The only record of the toxicity of sweet clover silage which has come to the attention of the authors is one by Roderick *et al.* (7). They reported that two spoiled samples were toxic to experimental animals. In view of the current interest in utilization of sweet clover as a silage crop, it was considered expedient to investigate the occurrence of an anticoagulant in sweet clover silage. This paper presents the results of one phase of this investigation.

MATERIALS AND METHODS

The determination of prothrombin time of blood of animals consuming sweet clover silage offered a means of detecting the presence of an anti-coagulant in the ration. Farmers' cattle, which were being fed sweet clover silage as the sole roughage, and control herds not receiving sweet clover silage, were used as the experimental animals. This approach had the advantage that farmers could be warned and could take corrective measures if prothrombin time was adversely affected.

Six herds of cattle near Nipawin and the University of Saskatchewan herd were made available for the tests. The management of these herds differed in several respects as indicated in Table 1.

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[1] Joint contribution from Dominion Forage Crops Laboratory, Saskatoon, and Department of Physiology, University of Saskatchewan, Saskatoon.

[2, 3] Officer-in-Charge and Agricultural Research Officer in charge of clover investigations, Dominion Forage Crops Laboratory, respectively.

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TABLE 1.—DESCRIPTION OF CATTLE, FEEDING AND MANAGEMENT

Herd designation*	Breed	Milking or dry	Forage fed
A	Holstein	Milking	Silage, sweet clover, stack silo No. 1
B	Holstein	Dry	Silage, sweet clover, stack silo No. 2
C	Hereford	Milking and dry	Silage, sweet clover, trench silo
D	Holstein	Milking	Hay, alfalfa and brome
E	Holstein, Ayrshire and Hereford	Milking and dry	Hay, grass-alfalfa; oat hay, sweet clover hay (good quality)
F	Shorthorn	Milking and dry	Hay, (oat sheaves)
G	Holstein, Shorthorn	Milking and dry	Hay, alfalfa and grass; straw

* Herds A to F (incl.) from the Nipawin area; herd G from Univ. of Sask.

In addition to the roughages listed in Table 1, the animals in herds A, B, and C were fed small quantities of alfalfa screenings from a seed cleaning plant during the latter phase of the investigation. Milking animals in all herds were being fed grain.

Blood samples were taken with a syringe from the jugular vein and 9 cc. were then gently shaken in a test-tube containing 1 cc. of 0.11 M. sodium citrate. The measurement of clotting time was based on the method developed by Quick *et al.* (5) and modified by Campbell *et al.* (2). This method involves the determination of the time required for the clotting of recalcified plasma in the presence of an excess of added thromboplastin under standard conditions.

Blood sampling was done on three dates. There was some uncontrollable variation in the handling of samples on different dates. For this reason data obtained on different dates of sampling are not considered to be strictly comparable. However, results obtained on any given date are comparable with each other.

EXPERIMENTAL RESULTS

Approximately one month after the feeding of silage commenced, blood samples were taken from cows in each of two herds being fed a silage ration and one herd being fed a hay ration. The results are given in Table 2.

TABLE 2.—PROTHROMBIN TIME OF BLOOD FROM TWO HERDS OF CATTLE AFTER FEEDING 4 TO 6 WEEKS ON SWEET CLOVER SILAGE COMPARED TO THAT FROM A HERD NOT FED SWEET CLOVER

Designation of herd	Breed	Roughage ration	No. of animals tested	Prothrombin time	
				Average	Range
A	Holstein	Silage	6	22.90 ± 0.42	22.0 – 25.0
C	Hereford	Silage	6	25.23 ± 2.10	19.8 – 33.8
D	Holstein	Hay	6	24.27 ± 0.26	23.2 – 25.0

TABLE 3.—INFLUENCE OF STAGE OF LACTATION AND OF EXPOSURE TO COLD ON PROTHROMBIN TIME. UNIVERSITY OF SASKATCHEWAN HERD. NO SWEET CLOVER FED IN ANY FORM

Breed	Condition and management	No. of animals	Prothrombin time in seconds	
			Average	Range
Holstein	Dry animals—loose pen barn	4	19.8 ± 1.00	17.1 to 22.6
Holstein	Dry animals—conventional barn	5	20.1 ± 0.82	18.0 to 22.2
Holstein	Milking animals—loose pen barn	5	20.3 ± 0.72	18.6 to 22.4
Shorthorn	Dry—outside continuously	5	17.4 ± 0.32	16.5 to 18.4
Shorthorn	Milking—outside continuously	5	19.5 ± 0.29	18.6 to 20.4

Analyses of the data by the t-test revealed that there were no significant differences between herds ($P < 0.05$). However, two of the cows in herd C had prothrombin times of 30.0 and 33.8 seconds, respectively. These two animals were the only ones among those tested which were not milking and which were without shelter at night. Lepp, Chubaty and Jaques (3) have shown that the susceptibility of rabbits to dicumarol is increased by exposure to cold and that in the absence of dicumarol the prothrombin time of rats may increase due to exposure to cold. Thus it appeared possible that the higher prothrombin time of the two animals in herd C might have been due to, or influenced by, exposure to cold. Furthermore, the possibility existed that dry animals normally had higher prothrombin time than milking animals, or that milk secretion provided an avenue for at least partial elimination of an anticoagulant which might be present in the ration. The data obtained did not provide evidence on any of these possibilities.

In order to secure information on the possible effects on prothrombin time of exposure to cold and of stage of lactation, certain animals in the University of Saskatchewan herd were tested. This herd was not being fed sweet clover in any form. The results of this study are given in Table 3.

There were no significant differences in prothrombin time between the groups in the University herd. This study established that in the absence of sweet clover in the ration there was no difference in prothrombin time between milking and dry animals and that there was no rise in prothrombin time due to exposure to cold. These results suggested that the higher prothrombin time of the two animals in herd C in the former test might have been due to the presence of an anticoagulant in the ration.

When the test herds in the Nipawin area had been on sweet clover silage for eight to ten weeks, more extensive sampling was done. As a check at that time sampling was done on animals in three separate herds (D, E and F) which were not fed sweet clover silage. The results are given in Table 4.

Use of the t-test revealed that highly significant differences ($P < 0.01$) existed between the mean prothrombin time of the control herds (D, E, F) and mean prothrombin time of each of herds A and B. The difference between the mean prothrombin time of herd A and of herd B was likewise

TABLE 4.—COMPARISON OF PROTHROMBIN TIME OF CONTROL ANIMALS WITH THAT OF ANIMALS FED SWEET CLOVER SILAGE FOR 8 TO 10 WEEKS

Designation of herd	Roughage ration	No. of animals tested	Prothrombin time in seconds	
			Average	Range
A	Silage—stack silo No. 1	20	44.05 ± 1.77	31.1 to 65.3
B	Silage—stack silo No. 2	15	33.75 ± 0.90	28.9 to 39.9
C	Silage—trench silo	30	29.44 ± 0.74	24.4 to 42.6
D, E, F	Hay and/or oat sheaves	19	30.25 ± 0.92	23.8 to 40.1

highly significant. However, the mean prothrombin time of herd C did not differ significantly from that of the control. Frequency distribution analysis of the data on the basis of the table of X (4) revealed that prothrombin time was significantly higher ($P < 0.05$) than the mean of the control herds in 16 of the 20 animals in herd A, two of the 15 animals in herd B, and one of the 30 animals in herd C.

In the data in each of Tables 2 and 3 inter-breed comparisons of prothrombin time are possible but significant differences cannot be shown. Although in the data in Table 4 breeds are confounded with rations to some extent, no inter-breed differences were apparent. It is thus considered valid to disregard the breed of the animals employed in this study.

The significant difference in prothrombin time between herd A, consisting of milking animals, and herd B, consisting of dry animals, conceivably could be due to one or a combination of the following factors: (1) the effect of stage of lactation, (2) a difference in quantity of feed consumed, (3) a difference in the quality of the feed. Evidence presented in Table 3 established that stage of lactation did not affect the prothrombin time of animals not fed sweet clover. Sweet clover silage was fed to herd C and no differences were apparent in the prothrombin time of dry and milking animals. On the basis of these observations, stage of lactation is not considered to have influenced the prothrombin time. The quality of the silage fed herd A was distinctly inferior to that fed to herd B. This is considered to be the primary reason for the difference found in prothrombin time, although a difference in volume of silage intake could have been a contributing factor.

DISCUSSION

Examination of the silos revealed that there were three distinct grades of sweet clover silage in each case. A mouldy layer, varying in depth from a few inches to a foot or more, occurred on the exposed face or faces of the silos. Interior to this mouldy layer the silage was a dark brown colour for a thickness of one to two or more feet. Interior to the dark-brown silage was the dark green, good quality silage.

For about 10 to 14 days prior to obtaining the data given in Table 4, the animals in herd A had been fed silage removed in horizontal layers from

the top of a stack silo. For this feeding period their ration consisted largely, if not entirely, of dark-brown silage. The silage for herd B was being removed in horizontal layers from a stack silo which had been in use for about two months. The dark-brown cap had been all consumed four to five weeks before securing the data given in Table 4. For a few weeks prior to this study, the animals in herd B had received a daily ration consisting of a mixture of dark-brown and good quality silage. The actual proportion of dark-brown silage being fed daily to herd B probably did not exceed 20 to 25 per cent of the roughage. In the trench silo from which herd C was fed, the dark-brown layer was confined to the upper surface. The silage was taken out in vertical layers so that the animals were fed dark-brown silage about one day per week.

Since the mouldy silage was largely, if not entirely, rejected by the animals, its effect was probably not serious. From the foregoing discussion, it is apparent that a relationship exists between prothrombin time and the amount of dark brown silage fed and the pattern of feeding silage of that quality. Prothrombin time was increased very materially when a large proportion of the total daily roughage consisted of dark-brown silage (herd A). Prothrombin time was significantly but less severely affected when dark-brown silage was fed daily, but constituted about 20 to 25 per cent of the roughage (herd B). No detrimental effect could be detected when dark-brown silage was fed about once per week, even though it constituted about 15 to 20 per cent of the total silage fed (herd C).

On the basis of these results it is concluded that an anti-coagulant had developed to toxic levels in the dark-brown sweet clover silage. It is likely also that it had developed in the mouldy silage. The normality of prothrombin time in herd C indicated that in good quality silage the anti-coagulant was either absent or present in sub-toxic quantities.

The work of Smith and Brink (9) established the relationship between coumarin and the toxic principle (anticoagulant) in sweet clover. Campbell *et al.* (1) and Stahmann *et al.* (10) proved that the anticoagulant present in toxic sweet clover hay is dicumarol. It is assumed that dicumarol was the anticoagulant present in the silage used in this study. This assumption is supported by the fact that chemical analysis has revealed the presence of dicumarol in the mouldy and dark-brown portions of the silage fed to herd A. Detailed results of the analysis of the silage samples for dicumarol will be presented in a later paper.

The normality of prothrombin time of herd C may seem to be at variance with the assumption that dark-brown sweet clover silage contains an anticoagulant. However, Roderick *et al.* (7) found that there was no change in clotting time when cattle were fed spoiled sweet clover hay and good alfalfa hay alternately every two weeks. They suggested that toxic material should not be fed more than one-third of the time. As noted previously, herd C consumed dark-brown silage about once per week. Assuming that an anticoagulant was present in this silage, on the basis of the results of Roderick *et al.* (7) it is considered that the feeding of good quality silage about six-sevenths of the time nullified the effect of the anti-coagulant. It should be noted that Smith (8) showed that alfalfa fed continuously with spoiled sweet clover hay had no therapeutic value.

The wide variation in prothrombin time between animals, in herd A in particular, requires some explanation. Although to some extent this variation may be due to differences in volume of silage intake, it is considered to be due mainly to inherent differences between animals in susceptibility to the dicumarol. Such differences have been shown by work of Roderick *et al.* (7), Smith (8), and Campbell *et al.* (2).

It would appear to be highly important to minimize the development of dark-brown and mouldy silage when using sweet clover as a silage crop. Other things being equal, trench or horizontal or well constructed upright silos will afford a lower proportion of inferior silage than will stack silos. The employment of well established practices of silage production, such as controlling the moisture content of the crop as ensiled, chopping finely and packing heavily, should be aids to this end. Finishing off the silo with a layer of at least two or three feet of silage from some other crop should largely, if not completely, prevent the mouldy and dark-brown layers from developing in the sweet clover silage.

ACKNOWLEDGMENTS

This study was made possible by the co-operation of staff of the Physiology Department, College of Medicine, University of Saskatchewan. For generous advice and guidance, and for placing equipment and staff at our disposal, we are deeply indebted to L. B. Jaques, Professor and Head of the Department of Physiology. Our grateful acknowledgment is extended to Erica Froese, Department of Physiology, for her advice and for her work in determining prothrombin time on some of the samples. The assistance of J. L. Millar, Animal Diseases Laboratory, University of Saskatchewan, and W. F. McDougall, Veterinarian, Nipawin, Saskatchewan, in drawing the blood samples is gratefully acknowledged. Due thanks are expressed to J. M. Bell, Animal Husbandry Department, for his constructive criticism of the manuscript.

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RAPESEED OIL MEAL IN BROILER RATIONS WITH OBSERVATIONS ON THE NATURE AND CONTROL OF ITS METABOLIC INHIBITORS[1]

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[Received for publication June 23, 1954]

ABSTRACT

The substitution of 17 per cent rapeseed oil meal for the soybean oil meal component of a broiler ration produced birds of equivalent weight and quality at 12 weeks to those on the control diet. The inclusion of iodide at a level of 3 p.p.m. (calculated as iodine) controlled the goitrogenic and anti-thyroid effects of the rapeseed meal. The criteria of response were body weight, skeletal growth, carcass quality, feed efficiency, thyroid gland histology and metabolic rate (as indicated by plasma protein-bound iodine values). No detrimental effects of feeding rapeseed meal were observed during three trials.

Because iodide inhibited both the goitrogenic and anti-thyroid effects, it is suggested that the goitrogenic principle involved is a thiocyanate rather than a thiocarbamide substance.

INTRODUCTION

Reports concerning the effects of rapeseed oil meal[2] as a component of experimental diets are inconsistent. Anti-thyroid effects (5) (8) (9) (11) (15) (17) (26) (28) and both growth depressing (7) (10) (21) (22) (30) and growth promoting effects (1) (14) (18) have been observed and the intensity of these effects has been influenced by the level of the test material employed (7) (15) (22) (26) (30). Sample variation may also have been a factor causing these inconsistencies.

An anti-thyroid principle identified as *l*-5-vinyl-2-thiooxazolidone has been isolated from rapeseed (5) (11) and a goitrogenic effect has followed the feeding of rapeseed meal but not the seed oil (26) (28). Varying degrees of success have followed attempts to control the goitrogenic action of this principle by limiting its level in the diet (8) (22); by adding iodide (1) (24), diiodotyrosine or thyroxine (24) to the ration; and by cooking (29), steaming (16) or hot water extraction of the meal (1). Ethanol extraction has reduced the goitrogenic effect (15).

The glucosides, sinigrin and gluconapin, have been isolated from rapeseed (2) and from rapeseed meal (14) (21) and these compounds are known to be the precursors of the toxic principles, allyl and crotonyl isothiocyanate (2) (14) (21) (25). French and Swedish workers have shown that extraction of the meal with 70 per cent ethanol mitigates the toxic symptoms attributed to these compounds (15) (21).

Short term feeding trials conducted in this laboratory (1) showed that high levels of rapeseed meal in chick starter rations produced birds heavier than the corresponding controls and the increased gains were accompanied by an enhancement of feed efficiency. These results were obtained with

[1] Contribution No. 260 from the Chemistry Division, Science Service.

[2] In the interests of brevity, the expressions "rapeseed meal" and "soybean meal" are used subsequently to designate these substances.

untreated meal as well as with meal in which the anti-thyroid principle had been neutralized by the inclusion of a low level of iodide or by extraction with hot water. Toxic symptoms developed from only one sample of rape tested but these symptoms were prevented by the same treatments used to overcome the anti-thyroid effect of the meal. Because rapeseed meal appeared in preliminary trials to be a satisfactory protein supplement for chicks, it was decided to test its usefulness in broiler-type rations and to investigate its goitrogenic properties.

PROCEDURE

Replicate lots of day-old cross bred chicks were placed on test for 12 weeks. The chicks were allowed to feed ad libitum on the diets given in Table 1. Variations in the basic diets with respect to the amounts of added inorganic iodide are shown in Table 2. Scattered feed was recovered daily to allow computation of feed/gain ratios. On the terminal dates the birds were weighed and killed and the carcasses graded after overnight chilling. Thyroid glands were weighed and sections were prepared from representative glands for histological study. Pooled plasma from each group was analysed for protein-bound iodine (PBI) by the method of Barker *et al.* (6). Three trials were conducted in 1952 and 1953 involving two breeds of birds.

TABLE 1.—COMPOSITION OF EXPERIMENTAL DIETS

Ingredient	Trials 1 and 2		Trial 3	
	Basal A	Rape 17%	Basal B	Rape 15%
	%	%	%	%
Ground yellow corn	54.2	54.2	35.8	31.8
Soybean oil meal	17.1	—	11.0	—
Rapeseed oil meal (expeller)	—	17.1	—	15.0
Wheat middlings	5.0	5.0	—	—
Ground wheat	—	—	31.8	31.8
Cerograss	5.0	5.0	2.5	2.5
Fish meal (65%)	6.0	6.0	8.0	8.0
Meat meal (50%)	4.0	4.0	—	—
Meat and bone scraps (50%)	—	—	8.0	8.0
Brewer's yeast	5.0	5.0	—	—
Ribo-4	—	—	2.0	2.0
Salt (iodine-free)	0.5	0.5	0.5	0.5
$Ca_3(PO_4)_2$	1.4	1.4	—	—
$CaCO_3$	1.5	1.5	—	—
$MnSO_3 . 4H_2O$	0.019	0.019	0.025	0.025
Choline	0.044	0.044	0.053	0.053
Nicotinic acid	—	—	0.002	0.002
Vitamin B_{12} and antibiotic feed supplement[1]	—	—	0.05	0.05
Sulphaquinoxaline	—	—	0.013	0.013
Vitamin A I.U./100 lb.	108,960	108,960	90,800	90,800
Vitamin D I.U./100 lb.	18,160	18,160	31,780	31,780
Productive energy (Cal./lb.)[2]	869	919	950	951
Digestible protein (lb./100 lb.)[2]	17.6	16.5	18.2	18.5

[1] 12.5 mgm. B_{12}/lb. and 2 gm. procaine penicillin.
[2] Calculated from the data of Fraps (13).
The iodine content of these diets (3 p.p.m.) was contributed mainly by the fish meal component.

RESULTS

The effects of feeding rapeseed meal on the body weight, bone growth and carcass quality of broilers are shown in Tables 2 and 3. The results of the three trials showed that rapeseed meal satisfactorily replaced the

TABLE 2.—TREATMENT EFFECTS IN TWELVE-WEEK BROILER TRIALS

Trial[1]	Treatment[2]		No. birds	Av. body wt.	Av. feed consumed	Feed gain	Av. tibia length
	Diet	I_2					
		p.p.m.		gm.	gm.	gm./gm.	mm.
1	Basal A	3	20	1128	3803	3.5	119.6
	17% rape	3	20	1576[4]	4881	3.2	128.2[4]
	17% rape	9	20	853	3269	4.0	109.7
	17% rape	17	20	1216[3]	4075	3.5	122.5
	17% rape	33	20	1106	3673	3.5	116.9
2	Basal A	3	18	1290	4658	3.7	
			17	1372	4634	3.5	121.8
	17% rape	3	15	1338	4521	3.5	
			16	1287	4197	3.4	123.4
	17% rape	120	19	1216	4335	3.7	
			19	1144	3951	3.6	118.6
3	Basal B	3	9	1944	5876	2.7	144.0
			8	2068	—	—	142.7
			10	1818	5038	2.6	141.7
			9	1831	—	—	140.8
	18% rape	3	10	1871	5503	2.7	144.5
			8	1950	—	—	145.2
			9	1763	5304	2.7	139.2
			7	1863	—	—	141.8

[1] Trials 1 and 2, NH × BBW; trial 3, NH × BR birds.
[2] Iodine values above the dietary level of 3 p.p.m. were obtained by the addition of KI. Possible loss of iodine on storage was avoided by frequent compounding of rations.
[3] $P < 0.05$ } in comparison with group fed Basal A.
[4] $P < 0.01$ }

TABLE 3.—CARCASS GRADES OF TWELVE-WEEK-OLD BROILERS

Trial	Treatment		No. birds	Carcass grades in per cent					
	Diet	I_2		Flesh			Fat		
				Sp[1] + A	B	C	Sp + A	B	C
		p.p.m.							
1	Basal A	2	20	18	59	23	0	29	71
	17% rape	3	20	94	6	0	88	12	0
	17% rape	9	20	18	47	35	0	6	94
	17% rape	17	20	47	47	6	29	24	47
	17% rape	33	20	71	23	6	30	35	35
2	Basal A	3	35	44	53	3	44	50	6
	17% rape	3	31	36	64	0	36	64	0
	17% rape	120	36	26	71	3	29	66	5
3	Basal B	3	36	37	63	0	63	31	6
	15% rape	3	34	37	63	0	60	40	0

[1] Special.

soybean meal component of the two rations under study. In one trial the rapeseed meal diet was more effective than the basal diet. Even when compared with the high energy diet B the rapeseed meal diet produced birds of equivalent weight and quality. Contrary to reported findings, no inhibition of appetite (28) nor impairment of feed efficiency (12) resulted from the inclusion of this relatively high level of rapeseed meal in the diet. No deaths due to treatment occurred in any of the trials but birds were removed from time to time from all groups in trials 2 and 3 owing to the occurrence of leg weakness.

It is apparent that iodide at the level of 3 p.p.m. (as I_2) contributed by the fish meal component of the ration effectively controlled the anti-thyroid action of the rapeseed meal. Except for an inhibitory effect on growth when the iodide level was raised to 120 p.p.m. no deleterious effects due to added inorganic iodide were observed in these trials. No advantage was apparent for iodide levels above 3 p.p.m.

The data in Table 4 show that the inclusion of rapeseed meal at moderate levels in a diet containing a low but adequate level of iodide did not adversely influence thyroid function. Significant increases in thyroid gland weight and in follicular and lumen diameters resulted from the rape treatment but the effect on epithelial cell height was variable. The magnitude of these changes was indicative of some degree of thyroid hypertrophy and of colloid storage. However, although the histological picture was one of mild hypothyroidism, the plasma PBI values showed no treatment effect of rapeseed meal on the thyroxine secretion of the gland. However, a significant rise in plasma PBI occurred when the dietary iodide level was raised to 120 p.p.m. Lever (19) states that the ratio (d/n) of the follicular lumen diameter (d) to the number (n) of follicular epithelial

TABLE 4.—TREATMENT EFFECT ON THYROID HISTOLOGY, THYROID GLAND WEIGHT AND PBI[1]

Trial No.	Treatment		Follicular diam. (D)	Lumen diam. (d)	No. epithelial cells	$\frac{d}{n}$	Epithelial cell height	Thyroid wt. / body wt.	Plasma PBI[1]
	Diet	I_2							
		p.p.m.	μ	μ	n		μ	gm./100 gm.	μg./100 ml.
1	Basal A	3	68.8	61.4	23.1	2.7	3.6	5.7	—
	17% rape	3	109.7[4]	101.2[4]	34.4	3.0	4.3[4]	17.3[4]	—
	17% rape	9	84.8[3]	77.2[3]	29.8	2.6	3.8	10.8	—
	17% rape	17	88.2[3]	80.1[3]	26.7	3.0	3.8	14.1	—
	17% rape	33	77.5	67.8	27.3	2.5	4.4	12.8	—
2	Basal A	3	A high incidence of nodular thyroids showing atrophic degeneration and almost complete loss of colloid was observed in all groups in this trial[2].					6.2	2.2
	17% rape	3						11.6	1.7
	17% rape	120						14.9	6.9
3	Basal B	3	82.2	75.2	—	—	3.5	10.1	3.1
	15% rape	3	93.5[4]	84.1[4]	—	—	4.7[4]	16.4[4]	3.0

[1] PBI Protein-bound iodine.

[2] Because the incidence of nodular tissue was much greater in the basal group it can be concluded that the condition was not due to rapeseed meal.

[3] $P < 0.05$.

$P < 0.01$.

cells is indicative of the state of activity of a thyroid gland. The tabulated $\frac{d}{n}$ values confirmed the finding that the rapeseed meal diets caused little, if any, change in thyroid function. It would appear, therefore, that reliance on changes in gland weights alone could lead to false conclusions. In this interpretation the authors are in agreement with Hart.*

DISCUSSION

These trials showed that, provided sufficient iodide was present, the substitution of rapeseed meal for soybean meal in broiler rations produced equally favourable results in terms of body weight gain, skeletal growth and carcass quality. These results confirmed earlier findings with young chicks (1). It was concluded that the substitution of rapeseed meal in a growing ration of average quality promoted adequate or superior growth and fattening. When substituted in a higher energy ration, rapeseed meal maintained optimum growth.

The observed differences in growth effect may have been associated either with the differences in the productive energies of the various rations or with differences in their protein quality. Although the rations for all of the trials contained adequate amounts of vitamin B_{12} in their fish and meat meal components, the rations used in trial 3 contained vitamin B_{12} and antibiotic feed supplement in addition. Increased feed consumption and improved feed efficiency, effects which are known to result from antibiotic supplementation of the ration, were obtained in trial 3 and these effects probably were partially responsible for the superior body weights obtained in this trial. The greater skeletal growth with proportionately less flesh and fat observed in trial 3 was probably due to the fact that the breed of chick used in this trial was faster growing than that used previously.

It has been shown that rapeseed contains an anti-thyroid principle and this principle has been isolated and identified as *l*-5-vinyl-2-thiooxazolidone. Goitrogenic activity has also been demonstrated for rapeseed meal but practically no activity has resulted from the feeding of the seed oil. The three trials reported above, as well as earlier trials involving untreated rapeseed meal, give further evidence of goitrogenic action. However, thiooxazolidone could not be demonstrated by spectrophotometric analysis of extracts of this meal, prepared according to the procedure outlined by Astwood (5). The seed from which this commercial sample was prepared was not available for analysis but, using the above procedure, thiooxazolidone was found in a different variety of rapeseed. Since the meal under test was strongly goitrogenic it may be concluded that a goitrogen other than thiooxazolidone was involved in these trials.

Free thiocyanate has been reported to be present in *Brassicae* (27), together with isothiocyanates (mustard oils) (21) (23) and cyanogenetic glucosides which may be converted to thiocyanate by the mammalian organism (4). Since thiocyanate is known to inhibit markedly the accumulation of iodide by the thyroid gland (27) (31) it is quite possible that the consumption of feed containing this substance would render iodine-

* Hart P. C. (*Personal communication*).

deficient a diet which otherwise would be adequate. The anti-thyroid action of thiocyanates is readily inhibited by increasing the iodide intake (3). Although iodide also inhibits the thyroid hyperplasia caused by a thiocarbamide (12) (20), low levels do not inhibit the decline in metabolic rate caused by this goitrogen (12). The trials reported above, as well as earlier trials with young chicks (1), show that low levels of iodide not only inhibit the goitrogenic effect of the rapeseed meal but also permit the maintenance of a normal metabolic rate, as measured by determination of the PBI level of the blood. Since both the goitrogenic and anti-thyroid actions of thiocyanate are inhibited by low levels of iodide it can be concluded that the active goitrogen in the rapeseed meal used in these trials is a thiocyanate rather than a thiocarbamide or related compound.

No toxic effects were apparent in these trials with a rapeseed meal ration containing iodide and toxic effects observed in earlier trials with young chicks (1) were mitigated by the inclusion of iodide in the ration. It is known that the glucosides present in rapeseed are the precursors of toxic isothiocyanates and it is reasonable to assume that the toxicity of these compounds as well as their goitrogenic action have been nullified by the inclusion of iodide in the ration. It had been shown earlier that hot water extraction of the rapeseed meal also prevented the development of toxic effects, presumably due to the removal of the soluble glucosides.

The variations which have been reported concerning the effects of feeding rape seed and rapeseed meal may be due to differences in the reactions of the test animals involved or to variations in the relative amounts of the toxic principles present. The well-known chemical instability of isothiocyanates could also account for the reported variations. It has been postulated that isothiocyanate could, upon enzymic oxidation, yield the thiocarbamate thiooxazolidone (23). Whatever reactions are involved in the transformation of isothiocyanates it is evident that the presence of iodide greatly reduces their toxic and anti-thyroid activity.

It is concluded that, provided sufficient iodide is present, rapeseed oil meal can be substituted for soybean oil meal in broiler rations.

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THE GENESIS OF THE ONEIDA SERIES IN SOUTHERN ONTARIO[1]

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[Received for publication June 30, 1954]

ABSTRACT

Particle size distribution, bulk density, organic matter, pH, exchangeable cations, and total chemical composition were determined for the genetic horizons of an Oneida clay loam—a Grey-Brown Podzolic soil developed from calcareous clay till. Because the pale brown A_{21} horizon contained less sesquioxides than the grey A_{22} horizon below, the colour of the former was attributed to a higher organic matter content. Carbonates had been removed completely from the solum, to a depth of 28 inches, although total chemical analysis showed that some weathering had taken place to a depth of 36 inches.

On the basis of calculations of the losses and gains within each genetic horizon, using the 0.25-1.0 millimetre sand fraction as the immobile constituent, it was concluded (1) that the entire solum suffered a net loss of 20 per cent by weight; (2) that iron, alumina, and silica were translocated from the A horizon to the B horizon; and (3) that only materials having a particle size less than 0.5 micron (fine clay) accumulated in the B horizon, during soil development.

Soils are classified in the field on the basis of the observable characteristics of their profiles. In some instances, field observations permit interpretation of the genesis of the soil but more commonly laboratory analyses as well as field study of the profile are necessary for satisfactory characterization of the genesis of the soil. The purpose of this paper is (*1*) to characterize the Oneida soil profile by physical and chemical means; (*2*) to devise a technique by which changes that have occurred during soil development can be measured quantitatively, and (*3*) to use these results to evaluate some of the theories of genesis that have heretofore been based mainly on field observations.

DESCRIPTION OF THE ONEIDA SERIES

The Oneida series comprises about 168,000 acres in Southern Ontario. It occurs extensively in the southern part of Peel County, where it has developed on a fluted glacial till plain deposited by the Lake Ontario lobe of the Wisconsin glacier, and in Lincoln County, where it has developed on the Vinemount moraine (4). The series consists of well drained soils developed from calcareous till on smooth moderately sloping topography.

The Oneida series has been classified as a Grey-Brown Podzolic soil. It resembles the central concept of the Grey-Brown Podzolic great soil group in Canada, in that the A_2 horizon can be divided into an upper A_{21} that is more brownish than the lower part, the A_{22}. The A_{21} horizon is considered by most soil pedologists in Ontario to be the B horizon of a Podzol profile developing above the B horizon of the Grey-Brown Podzolic soil. These so-called double profiles have been discussed by Stobbe (13) in Ontario and Cline (5) in New York.

[1] Condensation of a thesis submitted to the Graduate School, University of Toronto, by the senior author in partial fulfilment of the requirements for the degree of Master of Science in Agriculture.

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A soil profile, considered to be representative of the Oneida series, was chosen from a woodlot of beech and oak in Peel County, Toronto Township, Concession I, Lot 4. The following is a description of the soil profile, taken at the time of sampling:

A_0 – 0.5-0 inches; very dark grey-brown (10 YR 3/2)* organic layer.

A_1 – 0-1.5 inches; very dark grey (10 YR 3/1) clay loam; very high in organic matter; very friable consistency; granular structure; pH 5.0.

A_{21} – 1.5-5 inches; very pale brown (10 YR 7/3); clay loam; platy structure; extremely friable; gradational boundary; few stones; pH 5.1.

A_{22} – 5-10 inches; light grey (10 YR 7/2) clay loam; platy structure; very friable; gradational boundary; few stones; pH 5.1.

B_1 – 10-16 inches; light yellowish brown (2.5 YR 6/4) clay; coarse blocky structure; hard consistency when dry; gradational boundary; few stones; pH 5.2.

B_2 – 16-28 inches; grey-brown (10 YR 5/2) clay; prismatic stucture; hard consistency when dry; gradational boundary; stony; light brownish grey coating on the aggregates; pH 6.3.

C – 28-37 inches; light yellowish brown (2.5 Y 6/4); calcareous clay till; small sharp edged stones; pH 8.0.

C – 37-41 inches; light yellowish brown (2.5 Y 6/4); highly calcareous clay till; small sharp edged stones; pH 8.0.

C – 41-45 inches; light yellowish brown (2.5 Y 6/4); highly calcareous clay till; small sharp edged stones; pH 8.0.

* Munsell colour notation.

FIELD AND LABORATORY METHODS

A large rectangular pit was dug and core samples for bulk density determinations were taken from the central zone of each horizon. Additional samples were taken from each horizon for physical and chemical analyses. The soil samples were air-dried and ground to pass through a 10-mesh screen. After very thorough mixing, representative samples from the main sample of each horizon were placed in metal moisture cans and stored in a dessicator.

The soil cores were dried to constant weight at 105° C. and the bulk density determined by dividing the dry weight of the soil by the volume of the core.

The pipette method as outlined by Kilmer and Alexander (9) was used to determine the particle size distribution in each horizon. A 10 per cent solution of "Calgon"** was used as a dispersing agent, instead of the sodium hexametaphosphate solution prepared according to the above authors. The sodium carbonate fusion methods described by Hillebrand and Lundell (8) were used for total chemical analysis. Calcium and magnesium were determined in the leachate from the sesquioxide precipitation by the versenate method as outlined by Cheng and Bray (2) using sodium diethyldithiocarbamate to remove interfering ions (3).

** Trade name for a water conditioner containing sodium hexametaphosphate.

Sodium and potassium were brought into solution by treatment of a separate sample of soil with hydrofluoric acid followed by perchloric acid digestion (6). The sodium and potassium were determined by means of a Beckman flame photometer.

Total carbonates were determined by the Schollenberger method (12).

Organic carbon was determined by Walkley's modification of the Schollenberger method (14) and the organic matter content was calculated by multiplying the per cent organic carbon by the factor 1.724.

The pH was determined potentiometrically with the glass electrode in a 1 : 1 ratio of soil to water (11).

Loss of ignition was determined by heating the soil to constant weight in a muffle furnace at 850° C. (1).

RESULTS AND DISCUSSION

Physical Characteristics

The bulk densities of the Oneida soil profile, as shown in Table 1, increased with depth below the A_{21} horizons. The greater bulk density of the A_{21} relative to the A_{22} may be the result of compaction or accumulation of material leached from the A_1 into the interstices of the A_{21} horizon. The relatively small bulk density of the A_1 was the result of accumulation of organic matter. The bulk density of all horizons in the solum was smaller than the bulk density of the C horizon, presumably due to the removal of carbonates from the solum. Removal of carbonates presumably did not result in a collapse of the structure of the soil layers; hence the loss of carbonates increased the porosity and decreased the bulk density of the solum.

It follows, therefore, in view of the 27.5 per cent carbonates ($CaCO_3$ equivalent) in the parent material (i.e. 12 per cent CO_2 as shown in Table 2) that the bulk density of the A_{21}, A_{22}, B_1 and B_2 horizons should be about 1.14. In fact, however, the bulk density of the A_{22} was only 1.05 while

TABLE 1.—PHYSICAL CHARACTERISTICS OF THE ONEIDA SOIL PROFILE

Horizon	Bulk density	Sand	Silt	< 2μ Clay	< 0.5μ Clay
		%	%	%	%
A_1	0.50	39.0	34.4	26.5	14.5
A_{21}	1.10	30.4	43.7	25.9	15.6
A_{22}	1.05	29.7	42.5	27.8	15.8
B_1	1.25	21.8	31.6	46.6	31.7
B_2	1.50	19.9	31.6	48.5	34.4
C 28″-37″	1.56	23.4	37.9	38.7	24.6
C 37″-41″	1.56	21.2	38.6	40.2	24.2
C 41″-45″	1.56	21.5	37.7	40.8	24.3

TABLE 2.—CHEMICAL ANALYSIS OF THE ONEIDA SOIL PROFILE

Horizon	Element								O.M.	Loss on ignition	pH	SiO_2/R_2O_3
	SiO_2	Al_2O_3*	Fe_2O_3	CaO	MgO	K_2O	Na_2O	CO_2				
	%	%	%	%	%	%	%	%	%	%		
A_1	56.71	9.13	2.91	2.37	1.03	1.81	1.67	—	22.58	25.94	5.0	1.62
A_{21}	74.43	11.39	3.69	1.70	1.25	2.02	1.89	—	2.55	4.24	4.5	1.69
A_{22}	72.20	12.69	4.38	1.60	1.46	2.10	1.91	—	1.55	3.67	4.1	1.46
B_1	66.80	14.99	6.16	1.67	1.94	2.77	1.95	—	0.87	4.75	5.2	1.10
B_2	63.69	16.27	6.79	1.87	2.40	3.15	2.03	0.05	0.62	4.21	6.3	0.96
C 28″-37″	51.38	12.53	4.92	12.90	2.27	2.70	2.04	10.12	0.28	12.17	8.0	1.02
C 37″-41″	46.56	11.41	4.57	16.22	2.48	2.52	1.78	12.20	0.28	14.82	8.0	1.02
C 41″-45″	46.11	11.50	4.49	16.82	2.52	2.49	1.92	12.14	0.28	14.82	8.0	1.00

* Includes TiO_2.

the bulk density of the B_2 was 1.50. Obviously something in addition to carbonates was lost from the A_{21} and A_{22} horizons while something has replaced some of the lost carbonates in the interstices of the B_2 horizon.

The particle size distribution of each horizon reported in Table 1 shows that the clay content (less than 2μ) of the A_{21} and A_{22} horizons was much lower than that of the C horizon while the clay content of the B_1 and B_2 horizons was higher. Clay size material apparently was lost from the A_2 horizons and accumulated in the B horizons. The clay fraction less than 0.5 microns in size showed a similar result. Data for other size fractions of clay are not reported here but they indicate that some fractions may have been translocated within the profile and others not.

Chemical Characteristics

The results of the chemical analysis of the Oneida soil profile are shown in Table 2. The 37-41 and 41-45 inch layers differed from the 28-37 inch layer in chemical composition, particularly in the content of silica, alumina and calcium. Although the 28-37 inch layer appeared, in the field, to be unweathered and similar to the layers below, it had lost appreciable amounts of carbonates. It is apparent that unaltered parent material or C horizon material may be appreciably deeper than many workers have described. The necessity of sampling to sufficient depth to obtain unaltered soil material for pedological studies cannot be overemphasized.

The A_1 horizon had a greater calcium content than the A_2 and B horizons presumably as a result of the return of calcium in the forest litter. The A_1 horizon was more than one unit lower in pH than the B_2 horizon yet the former contained more calcium by virtue of the high exchange capacity of the organic matter. The exchange capacity of the A_1 horizon was 43.72 m.e./100 grams while that of the B_2 horizon was only 14.45 m.e./100 grams.

The carbonates had been leached completely from the profile down to the B_2 horizon which contained only 0.05 per cent carbon dioxide. The method for determining carbonates did not permit the determination of the proportion of calcium carbonate to magnesium carbonate.

The data in Table 2 show that the percentage of iron and alumina in the A_{22} was greater than that in the A_{21} horizon. The silica : sesquioxide ratio also indicates that greater leaching of sesquioxides had taken place from the A_{21} horizon than from the A_{22} horizon. The organic matter content of the A_{21} horizon, however, was considerably greater than that of the A_{22} horizon. It is suggested that the pale brown colour of the A_{21} horizon was due to organic matter that had moved downward from the A_1 horizon by leaching. Moreover, it is the opinion of the authors that the A_{21} horizons of many of the Grey-Brown Podzolic soils in Ontario differ from the A_{22} horizons only in their content of organic matter and that the browner colour of the A_{21} horizon relative to the A_{22} horizon is not due to additional iron oxide in the former.

QUANTITATIVE DETERMINATION OF CHANGES DURING SOIL DEVELOPMENT

In making genetic interpretations of chemical and physical data reported as weight percentages of the soil horizons, it is assumed that the

horizons of the solum have developed from material similar to the unaltered soil material of the C horizon. In view of the rather widespread occurrence of overwash varying from 6 inches to 3 feet in depth over till or lacustrine materials in South-western Ontario, the validity of this assumption may be questioned.

Furthermore, on a weight percentage basis a decrease in one constituent necessitates an increase in the percentage of all other constituents. Loss of calcium from a given horizon could result in an apparent gain in silica in that horizon when in reality no gain had occurred.

It was desirable, therefore, to calculate actual losses and gains of soil constituents in the several horizons as well as in the entire profile. Haseman and Marshall (7) outlined a method in which the content of zircon and bulk density of each horizon was used to calculate the original weight and composition of a soil layer from which a given genetic horizon of the profile had developed. Hence, absolute losses and gains of the soil constituents were calculated.

The mineralogical determination of zircon is long and tedious. It seemed reasonable to assume, however, that the coarse sand fraction of soils in Ontario had undergone little weathering or translocation and, therefore, could be used as an immobile constituent instead of zircon. Calculations using the coarsest sand fraction present in quantity instead of zircon as the immobile constituent led Haseman and Marshall (7) to essentially the same conclusions with regard to the genesis of their particular soil. The 0.25-1.0 mm. sand fraction was used as the immobile constituent in this study. Calculations of losses and gains were made according to the following equations:

$$W'a = Wa \frac{Sa}{Sp}, \quad W'b = Wb \frac{Sb}{Sp}, \text{ etc.}$$

where W' = original weight of the horizon = bulk density in grams per c.c. of parent material $\times$ thickness in centimetres of original horizon.

W = present weight of the horizon = bulk density in grams per c.c. of present horizon $\times$ thickness in centimetres of present horizon.

S = percentage of 0.25-1.0 mm. sand by weight in present day layers.

a, b, etc. = subscripts indicate horizon to which the above symbols refer.

P = parent material.

The change in weight of any soil constituent in a given layer = weight of the layer now $\times$ percentage of the constituent in the layer $-$ original weight of the layer $\times$ percentage of the constituent in the parent material.

LABORATORY PROCEDURE

The 0.25-1.0 mm. sand fraction was separated from the soil by wet sieving. The sand was treated with dilute hydrochloric acid to destroy carbonates. It was then washed free of chlorides, dried, weighed and analysed for silica, sesquioxides and calcium according to the methods described previously.

RESULTS AND DISCUSSION

The results of the analysis of the sand fraction are shown in Table 3. The silica contents of the fractions from the different horizons were the same, within experimental error. The sesquioxide content of the A_{21} and A_{22} horizons was the same as that of the 37-41 inch and 41-45 inch layers. The relatively greater sesquioxide content of the fraction from the B horizon was due to coatings on the sand grains and not to a difference in the composition of the sand itself. The chemical composition of the sand fraction was considered to be uniform throughout the profile and therefore it was safe to assume that the solum developed from uniform material similar to that of the C horizon at the 41-45 inch depth. Differences between horizons, therefore, were a result of genesis and were not inherited depositional differences.

TABLE 3.—CHEMICAL ANALYSIS OF THE 0.25-1.0 MM. SAND FRACTION* OF THE ONEIDA SOIL PROFILE

Horizon	Per cent of whole soil	SiO_2	R_2O_3	CaO
		%	%	%
A_1	10.01	—	—	—
A_{21}	7.11	82.59	11.65	2.06
A_{22}	7.67	78.23	11.17	2.21
B_1	5.07	79.70	13.05	3.12
B_2	5.11	77.90	15.77	2.59
C 28″-37″	4.01	—	—	—
C 37″-41″	4.09	75.28	11.46	3.49
C 41″-45″	4.05	78.87	12.29	3.64

* Treated with 0.2N HCl to remove carbonates.

The losses and gains within the Oneida soil profile calculated according to the equations above are shown in Table 4. The net loss per square centimetre cross-section of the profile was 39.43 grams or 20 per cent by weight. The B horizon lost more than 16 grams but per unit volume of original material the loss was less than half the loss from the A_1, A_{21} and A_{22} horizons. About 0.19 grams of carbonate (CO_2) per c.c. of original material was lost from each horizon of the solum. Hence, differences in carbonate loss do not explain the greater net loss from the A horizons compared to the B horizons.

Moreover all horizons of the solum had lost clay of 2 microns and less in size although the A horizons had lost much more than the B horizons. This may account for some of the difference in net loss between the A and B horizons. Calculations for the fine clay (less than 0.5 microns) show a gain in the B horizon has a loss in the A horizons. Undoubtedly, the fine

TABLE 4.—LOSSES AND GAINS IN GRAMS OF THE ONEIDA SOIL PROFILE

(One square centimetre cross-section)

Horizon	Whole soil	Clay	$< 0.5\mu$ Clay	Silt	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	CO_2	O.M.
A_1	− 3.75	− 1.90	− 1.16	− 1.49	− 1.45	− 0.21	− 0.49	− 1.00	− 0.13	− 0.08	− 0.11	− 0.76	+ 0.558
A_{21}	− 7.40	− 4.48	− 2.65	− 2.20	− 0.64	− 0.41	− 0.87	− 2.72	− 0.31	− 0.15	− 0.23	− 2.09	+ 0.202
A_{22}	−11.91	− 6.59	− 4.02	− 3.85	− 2.02	− 0.55	− 1.21	− 4.03	− 0.45	− 0.23	− 0.35	− 3.06	+ 0.136
B_1	− 4.78	− 0.85	+ 0.24	− 2.96	+ 1.73	+ 0.10	+ 0.12	− 3.68	− 0.23	− 0.09	− 0.06	− 2.89	+ 0.098
B_2	−11.78	− 1.34	+ 1.68	− 7.19	+ 2.48	+ 0.50	+ 0.79	− 8.71	− 0.35	− 0.18	+ 0.01	− 6.87	+ 0.120
C 28″-37″	+ 0.35	− 0.61	+ 0.20	+ 0.21	+ 2.04	+ 0.17	+ 0.41	− 1.34	− 0.08	+ 0.05	+ 0.08	− 0.68	+ 0.001
C 37″-41″	− 0.16	− 0.16	− 0.05	+ 0.08	0.00	+ 0.01	− 0.04	− 0.12	− 0.01	− 0.02	0.00	− 0.01	− 0.001
C 41″-45″	—	—	—	—	—	—	—	—	—	—	—	—	—
Net change	−39.43	−15.93	− 5.76	−17.40	+ 2.14	− 0.39	− 1.29	−21.60	− 1.56	− 0.70	− 0.66	−16.36	+ 1.114

clay in the B horizon has accumulated in the voids resulting from the removal of carbonates. This fact accounts for the relatively large bulk density and the relatively small net loss of the B horizon compared to the A horizons.

Calculation of the original thickness of the different horizons showed that A_1 horizon increased in thickness by 25 per cent but the A_{21} and A_{22} horizons decreased in thickness by about 20 per cent. The thickness of the B_2 horizon also decreased by 17 per cent. The net increase in thickness, and hence volume, of the A_1 horizon was presumably due to incorporation of organic matter and the net decrease in thickness of the other horizons of the solum was due to loss of carbonates and a subsequent collapse of some of the voids thus formed.

The net loss of nearly 20 per cent of the total clay (2 microns and less) in the solum is undoubtedly due largely to loss of carbonates of clay size. It is unlikely that much of this "clay" loss consisted of clay mineral material.

The data in Table 4 show that there were negligible losses of silica, iron, and alumina from the profile although the B_2 horizon has gained about 10 per cent in silica, 20 per cent in iron and 12 per cent in alumina. Losses of these constituents from the A horizons were sufficient to account for the gains in the B horizons.

Losses of CaO and CO_2 amount to more than 60 per cent of the weight originally present in the solum while MgO suffered a loss of 31 per cent of its original weight in the solum. About 13 per cent of the sodium and potassium originally present had also been lost from the solum. All of these losses were presumably due to leaching to the ground water.

The gain in organic matter amounted to over 200 per cent although most of this gain occurred in the A_1 horizon. The gain in organic matter in the A_{21} horizon was appreciably greater than the gain in the A_{22} horizon.

CONCLUSIONS

On the basis of the chemical data and the mechanical analysis it was apparent that alteration of the soil material had occurred down to a depth of three feet. It has heretofore been tacitly assumed that unaltered soil parent material occurred at about thirty inches in medium to fine textured soils of this general area. In pedological studies, therefore, samples must be taken well below the horizon that is usually called parent material.

It was concluded that the Oneida profile had developed from a uniform deposit of calcareous clay till. The use of the sand fraction as an immobile constituent for calculations of losses and gains during soil genesis and also as an indicator of uniformity of soil material proved to be a valuable aid in the genetic interpretation of the chemical and physical data.

On the basis of field observations the Oneida soil was classified as a Grey-Brown Podzolic soil. The data reported herein support this classification. The study revealed, however, that the finer texture of the B horizon compared to the A and C horizons was due to the translocation of material less than 0.5 micron in size rather than the whole clay fraction.

The bulk density of the B horizon was less than that of the C horizon in spite of the accumulation of fine clay in the former. Apparently the clay had accumulated in the voids resulting from the removal of carbonates. The gain in clay, however, was not sufficient to replace the weight of carbonates lost.

During soil development there was a net loss of most soil constituents, particularly carbonates. It was concluded that most of the carbonates lost were of clay size.

The pale brown A_{21} horizon contained organic material that had been leached from the A_1 horizon but it did not contain more sesquioxides than the light gray A_{22} horizon. Field examination of other soils in Ontario having similar horizons suggests that many of the A_{21} horizons differ from the A_{22} horizons only in colour that is due to the presence of organic matter. Additional studies of this kind may clarify the genesis of the A_{21} and A_{22} horizons.

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THE NUTRITIONAL VALUE OF FROST-DAMAGED AND EARLY-HARVESTED CEREAL GRAINS FOR SWINE[1]

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[Received for publication June 3, 1954]

ABSTRACT

Three digestion and nitrogen balance studies were carried out with weanling pigs to determine the influence of various degrees of frost damage and early harvesting upon the nutritional value of wheat and oats. The digestibility of the protein and of the gross energy of wheat was reduced significantly by severe frost damage and by early harvesting. The biological value (B.V.) of the protein of severely frost-damaged and early-harvested grain was higher than that of slightly frost-damaged or non-damaged wheat. This increased B.V. counterbalanced the decrease in digestibility so that no significant reduction in the net protein utilization (B.V. $\times$ digestibility) resulted from frost damage or early harvesting of wheat. The digestibility of the gross energy but not of the protein of oats was reduced significantly by frost damage. There was a significant linear relationship between the weight per bushel of wheat and digestible energy (therms per 100 pounds or TDN).

INTRODUCTION

The feeding of frost-damaged cereal grains to livestock and poultry is quite common during certain years in western Canada. In 1950-51 over 200,000,000 bushels of frost-damaged wheat of non-milling grades were available for feeding purposes in Canada. However, very little detailed information is available on the comparative feed value of frost-damaged and non-damaged grains, especially when such grains make up a large percentage of the total ration. It is well known that frost damage affects the protein quality of wheat as indicated by baking quality (16, 19, 26, and others). Whether frost damage affects the nutritional quality of the protein of grains is not known.

Practical feeding experiments have indicated that frost-damaged cereal grains are satisfactory feeds for swine, cattle, sheep, and poultry (9, 14, 21, 28, and 33). Their comparative value with non-frozen grains has been quite variable from experiment to experiment.

This paper reports the results of three digestion and nitrogen balance experiments with swine to study the influence of severity of frost damage and early harvesting of non-frozen grain upon protein quality and general feeding value of wheat and oats.

PROCEDURE AND EXPERIMENTAL RESULTS

Experiment 1

Four lots of frost-damaged Rescue wheat weighing 30 lb., 44 lb., 52 lb., and 58 lb. per bushel were used in Experiment 1. The 30- and 44 lb.-per bushel wheats were grown near Swift Current, Saskatchewan, and the 52- and 58 lb.-per bushel wheats were grown at Scott, Saskatchewan. Each wheat was finely ground prior to mixing the ration. Sufficient corn starch was added to each wheat to reduce the total protein (N $\times$ 6.25) content of the ration to approximately 11 per cent on an air-dry basis. Minerals

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and vitamins were added to each ration so as to eliminate any possible deficiencies of these nutrients. An antibiotic feed supplement (procaine penicillin G) was added to the rations at the rate of 0.5 per cent. The physical composition of the rations is shown in Table 1, and the chemical composition of the wheats and of the complete rations is shown in Table 2. The severely frozen grain (30 lb. per bushel) contained a higher percentage of total nitrogen, non-protein nitrogen, ether extract, crude fibre, and ash, and hence a lower percentage of nitrogen-free extract than the other three wheats. However, it cannot be concluded that these differences are due entirely to frost damage or stage of maturity at the time frost occurred as the grains were not grown in the same area. McCalla and Newton (22) have reviewed the literature and presented data on the effect of stage of maturity and frost damage on chemical composition of wheat. The data presented in Table 2 agree, with minor exceptions, with their data and conclusions.

Four weanling Yorkshire barrows of similar type and breeding were used in this experiment. Their average weight was 37 lb. at the beginning

TABLE 1.—THE PHYSICAL COMPOSITION OF THE RATIONS FED DURING EXPERIMENT 1

		Ration 1	Ration 2	Ration 3	Ration 4
Wt./bu. of wheat		30	44	52	58
Wheat	(lb.)	62	77	75	72
Starch	(lb.)	38	23	25	28
Minerals[1]	(lb.)	2	2	2	2
Procaine Penicillin G	(lb)	0.5	0.5	0.5	0.5
B-Vitamins[2, 3]	(gm.)	1.16	1.16	1.16	1.16
Vitamins A and D[4]					

[1] The mineral mixture was composed of:

Salt (common)	30 pounds
Ground limestone	50 pounds
Steamed bonemeal	20 pounds
$FeSO_4 \cdot 7H_2O$	100 grams
KI	7 grams
$MnSO_4$	7 grams
$CuSO_4$	7 grams
$CoCl_2$	3 grams
$ZnCl_2$	3 grams

[2] The B-vitamin mixture was composed of:

Thiamine	70 grams
Riboflavin	100 grams
Niacin	300 grams
Ca. Pantothenate	350 grams
Pyridoxine	80 grams
Folic acid	25 grams
Choline dehydrogen citrate	160 grams

[3] The B-vitamins used in the experiments reported in this paper were generously supplied by Hoffmann-LaRoche Inc., Nutley, N.J.

[4] Each pig received approximately 5000 I.U. of vitamin A and 500 I.U. of vitamin D daily in the form of fish liver oil.

TABLE 2.—THE CHEMICAL COMPOSITION OF THE WHEATS AND OF THE RATIONS USED IN EXPERIMENTS 1, 2, AND 3. (CALCULATED TO A 10 PER CENT MOISTURE BASIS)

	Weight per 1000 kernels	Weight per bu.	Protein (Nx6.25)	Non-protein nitrogen	Ether extract	Crude fibre	Nitrogen-free extract	Total ash	Ca	P	Energy
	gm.	lb.	%	%	%	%	%	%	%	%	Cal./gm.
Experiment 1											
Wheat No. 1	12.2	30	17.9	1.0	4.1	7.1	57.7	3.0	0.07	0.64	4.18
Wheat No. 2	14.2	44	15.0	0.4	2.4	4.2	66.5	1.9	0.06	0.44	4.00
Wheat No. 3	18.4	52	15.4	0.3	2.0	4.0	66.7	1.9	0.05	0.43	4.04
Wheat No. 4	23.2	58	15.9	0.3	2.2	3.5	66.7	1.7	0.05	0.46	4.00
Ration No. 1	—	—	11.2	—	2.6	4.4	68.3	3.5	—	—	4.14
Ration No. 2	—	—	11.5	—	1.8	3.2	70.2	3.3	—	—	4.04
Ration No. 3	—	—	11.2	—	1.5	2.9	71.0	3.4	—	—	3.96
Ration No. 4	—	—	11.6	—	1.7	2.6	70.8	3.3	—	—	3.94
Experiment 2											
Saunders Wheat No. 1	22.2	58	15.2	0.29	1.8	3.0	68.4	1.6	0.04	0.43	4.03
Saunders Wheat No. 2	31.5	66	15.7	0.08	1.8	2.4	69.0	1.2	0.04	0.32	4.00
Ajax Oats No. 3	24.4	30	13.7	0.18	4.6	13.5	54.6	3.2	0.09	0.30	4.24
Ajax Oats No. 4	25.2	40	14.4	0.02	4.7	10.8	57.1	3.0	0.07	0.35	4.26
Ration No. 1	—	—	15.7	—	1.6	2.8	66.7	3.2	—	—	3.97
Ration No. 2	—	—	16.4	—	1.6	2.3	66.6	3.1	—	—	3.92
Ration No. 3	—	—	14.5	—	4.6	12.4	53.9	4.9	—	—	4.14
Ration No. 4	—	—	15.2	—	4.6	10.4	55.0	4.8	—	—	4.16
Experiment 3											
Early-cut wheat (A)	11.9	41	11.8	0.13	1.5	4.1	70.6	2.0	0.04	0.48	3.93
Medium-cut wheat (B)	22.0	58	11.2	0.09	1.4	3.6	71.7	1.4	0.03	0.45	3.98
Severely-frozen wheat (C)	12.2	33	16.4	0.75	4.5	6.8	59.7	2.7	0.06	0.62	4.24
Medium-frozen wheat (D)	14.2	44	14.4	0.29	2.2	4.7	66.7	1.9	0.05	0.48	4.10
Ration A	—	—	11.2	—	1.5	4.0	68.7	4.5	—	—	3.86
Ration B	—	—	11.1	—	1.5	3.4	70.3	3.7	—	—	3.91
Ration C	—	—	11.2	—	2.7	4.1	68.6	3.4	—	—	4.12
Ration D	—	—	11.4	—	1.8	3.7	69.7	3.4	—	—	4.04

and 68 lb. at the completion of the experiment. Weanling pigs were used because it had been shown that on a constant level of protein intake the efficiency of nitrogen utilization for growth decreases as the pig increases in body weight (5, and 29).

Each digestion and nitrogen balance study was of 10 days' duration preceded by a 5-day preliminary period. A 4 × 4 Latin square design of experiment was employed to allot the four pigs to the four rations. Digestion and metabolism crates similar to those described by Bell (3) were used. The pigs were fed twice daily. The daily allowance of feed, which was mixed with approximately three times its weight of water, was fed according to each pig's appetite. This procedure was followed in order to obtain some indication of relative palatability of the wheats. Red ferric oxide was used to demarcate the feces corresponding to the feed fed during the collection period.

The feces were collected twice daily and dried in a forced-draft oven maintained at 58° C. The 10 daily collections of feces were composited at the end of each period, weighed, ground through a hammer mill, and then sampled for chemical analyses. The urine was collected in bottles containing a few drops of H_2SO_4. Each day a 1/10 aliquot was saved and stored in a refrigerator under toluene.

The methods of the A.O.A.C. (1) were used in the analyses of all feces, urine, and feed nutrients with the exception of total energy and phosphorus. The Parr oxygen bomb was used in the determination of total energy and the method of Snell and Snell (31) was used for phosphorus.

The B.V.'s of the proteins were calculated using the Thomas-Mitchell method (23) and metabolic fecal nitrogens (M.F.N.) were calculated from the data of Kehar and Mukherjee (20) obtained with rats. In this method M.F.N. is held to be a function of indigestible dry matter (D.M.) intake rather than total D.M. intake. It has been reported that M.F.N. varies to a greater extent with indigestible D.M. intake than with total D.M. intake (7, 8, 18, 20, 23, 24, 30). The calculated values for M.F.N. varied from 0.18 gm. per 100 grams D.M. consumed for a ration that was 91 per cent digestible to 0.24 gm. per 100 gm. D.M. consumed for a ration that was 80 per cent digestible. The value, 0.18 gm. M.F.N. per 100 gm. D.M. consumed, is the same as that found by Bell *et al.* (4) for a ration that was calculated* to be approximately 90 per cent digestible. Endogenous urinary nitrogen was calculated using the formula proposed by Brody *et al.* (10) and as discussed and used by Bell *et al.* (4 and 5). The values for urinary endogenous nitrogen obtained with this formula were checked with those using the formula proposed by Columbus (11) and were found to be approximately the same for pigs weighing 45 lb., but about 10 per cent greater for pigs weighing 80 lb. However, the B.V.'s obtained using the values obtained by Brody's or Columbus' formula were, for practical purposes, the same.

The results of this experiment are shown in Table 3. The digestibilities of the dry matter, organic matter, protein, ether extract, nitrogen-free extract, and total energy were lowered significantly ($P < 0.01$) by all degrees of frost damage. With the exception of the very severely frozen

*Authors' calculations.

TABLE 3.—AVERAGE FEED INTAKE, DIGESTIBILITY COEFFICIENT, AND NITROGEN UTILIZATION OF WHEAT RATIONS AS INFLUENCED BY FROST DAMAGE

	Ration No. 1	Ration No. 2	Ration No. 3	Ration No. 4	Necessary difference
					(p = 0.01)
Wt./bu. of wheat in ration (lb.)	30.0	44.0	52.0	58.0	—
Av. wt. pigs (lb.)	50.0	49.0	50.0	51.0	—
Av. daily feed intake (lb.)	2.1	2.4	2.5	2.5	—
Av. daily protein (N × 6.25) intake (lb.)	0.25	0.28	0.28	0.30	—
Av. daily gain of pigs (lb.)	0.4	0.7	0.6	0.7	0.1
% D.M. of ration digested	74.8	80.3	82.7	84.7	2.2
Digestibility Coefficients of Wheat[1]					
Dry matter	65.0	77.4	79.9	82.9	1.7
Organic matter	65.7	78.1	80.3	83.2	1.8
Protein (apparent)	55.7	69.0	71.8	76.7	3.1
Protein (true)[2]	69.2	80.6	83.8	86.8	3.4
Crude fibre	19.1	12.4	12.9	19.0	6.0
Ether extract	24.5	32.9	36.9	48.7	9.0
Nitrogen-free extract	80.6	87.1	87.5	89.6	1.9
Total energy	61.6	75.1	77.9	81.2	2.7
% Protein retain of feed (apparent)	23.4	31.8	25.9	33.2	4.0
B.V. of protein	64.7	62.4	53.8	57.0	6.8
Net protein utilization (B.V. × digestibility)	36.0	43.0	38.6	43.7	—
% T.D.N. in wheat	58.2	68.7	69.7	72.0	4.9
Digestible energy in wheat (therms/100 lb.)	114.1	136.4	142.9	147.5	5.7

[1] Assuming that the D.M. of starch was 95 per cent digestible and the D.M. of the mineral mixture 50 per cent digestible by the pig.
[2] Corrected for M.F.M.

wheat (30 lb. per bushel), the T.D.N. contents of the wheats were not significantly different. When evaluated in terms of digestible energy, the differences were significant in all cases at the 5 per cent level and in most cases at the 1 per cent level. The lowered digestibility of the severely frozen grains may be accounted for in part by their higher fibre content. It has been reported that there is a linear relationship between the crude fibre content of a ration and its digestibility by swine, amounting to between 1 and 2 per cent decrease in digestibility for each one per cent increase in crude fibre content (2, 17, and 27).

Although the apparent digestibility of the protein of the severely frozen wheat was significantly less than for the other three wheats, the portion digested was utilized to a greater extent. Whether this was due to the digested protein from the severely frozen wheat having a better balance of essential amino acids, is not known. It may be due to a greater economy of use of the digested protein, since less protein was available to the body. The net protein utilization (digestibility × B.V.) indicates that frost damage had no consistent effects on the value of the grain in meeting the protein needs of the body.

There were no significant differences between periods (i.e. ages of pigs) or pigs in the digestibility of the various chemical constituents studied. It has been shown that pigs between 50 and 200 lb. in body weight digest the various proximate analytical fractions of feedstuffs to about the same

extent (13, 29, and 32). There were no significant differences in this experiment in the B.V. of the protein between periods. That is, pigs weighing initially 37 lb. in body weight utilized the digested protein to the same extent as pigs weighing 68 lb.

It may be concluded that frost damage sufficient to cause a weight per bushel as low as 30 lb. reduced the utilization of the energy but did not reduce appreciably its protein value. Frost damage that caused a weight per bushel of 44 lb. did not reduce its protein or energy value as measured by T.D.N. when compared to the wheat weighing 58 lb. per bushel, but did reduce its energy value as measured by digestible energy. The pigs in this experiment did not consume as much of the ration containing the severely frozen wheat as they did of the other three rations.

In a study using mice as experimental animals, Bell and Gidyk (6) concluded that the feeding value of frost-damaged wheat was not impaired seriously until the weight per bushel was reduced to about 40 lb., but that the bulky nature of severely frost-damaged wheat prevented animals from consuming sufficient quantities of feed to make good gains.

Experiment 2

In Experiment 1 it had been shown that the digestibility of wheat was lowered by severe frost damage, but that the B.V. of the protein was increased. In that experiment starch was added to each wheat to result in a ration containing approximately 11 per cent protein. It was felt desirable to determine the digestibility and palatability of frost-damaged and non-frost-damaged wheat and oats in a more practical type of ration.

Two lots of Saunders wheat weighing 58 lb. and 66 lb. per bushel (the former was frozen and was graded as Feed, and the latter was not frozen and was graded as No. 2 Northern), and two lots of Ajax oats weighing 30 and 40 lb. per bushel (the former was severely frozen, and the latter was not frozen) were used in this experiment. The grains were finely ground and to each 95 lb. of grain were added 5 lb. of skimmilk powder and the same minerals and vitamins as added in Experiment 1. Aureomycin (Aurofac 2A)* was used in this experiment instead of penicillin.

Four barrow pigs, similar in breeding and type to those in Experiment 1, were used to evaluate the four rations by digestibility and nitrogen utilization studies. The pigs averaged 52 lb. in body weight at the beginning and 155 lb. at the completion of the experiment. The design of experiment, methods of feeding and collecting of feces and urine, and methods of chemical analyses and calculations, were the same as in Experiment 1.

The chemical composition of the grains used in making up the rations, and of the rations fed, is shown in Table 2. Results of this experiment are shown in Table 4. All rations proved to be very palatable and the pigs made satisfactory gains. As in Experiment 1, frost damage significantly reduced the digestibility of the dry matter, total energy, and protein of the wheat. In the case of the oats, the digestibility of the D.M. and total energy was significantly reduced but that of the protein was not affected.

* The aureomycin used in the experiments reported in this paper was generously supplied by Lederle Laboratories, Pearl River, N.Y.

TABLE 4.—FEED INTAKE, AVERAGE DIGESTIBILITY, AND NITROGEN UTILIZATION OF THE RATIONS AND GRAINS AS INFLUENCED BY FROST DAMAGE (EXPERIMENT 2).

	Ration 1	Ration 2	Ration 3	Ration 4	Necessary difference
	Wheat	Wheat	Oats	Oats	
					p = 0.01
Wt./bu. of grain in ration (lb.)	58.0	66.0	30.0	40.0	—
Av. weight pigs (lb.)	107.0	105.0	104.0	108.0	—
Av. daily feed intake (lb.)	5.7	5.1	5.6	5.8	—
Av. daily protein intake (lb.)	0.89	0.84	0.82	0.84	—
Av. daily gain of pigs (lb.)	1.7	1.6	1.3	1.8	0.2
% D. M. of ration digested	84.4	88.0	60.0	66.3	1.8
Digestibility Coefficient of Grain[1]					
Dry matter	84.6	88.9	58.6	65.4	1.8
Organic matter	84.8	89.0	60.6	66.6	1.9
Protein (apparent)	82.6	88.9	80.4	81.2	2.9
Protein (true)[2]	90.9	96.0	94.0	92.8	2.6
Crude fibre	17.9	22.5	13.2	15.4	9.0
Ether extract	42.1	50.6	78.4	78.6	9.6
Nitrogen-free extract	93.7	95.5	78.6	82.7	2.0
Total energy	84.6	88.4	62.0	68.1	1.8
% Protein retained of feed (apparent)	29.2	30.2	38.0	33.5	6.2
B.V. of protein or ration	44.6	42.8	58.6	52.3	9.9
% T.D.N. of grain	76.9	80.3	58.5	63.5	3.9
Digestible energy of grain (therms/100 lb.)	154.8	160.5	116.7	128.8	4.6

[1] Assuming that the O.M. and protein of skimmilk powder were 98 per cent digestible by the pig.
[2] Corrected for M.F.N.

The B.V. of the protein of the frozen grain was higher than that of the non-frozen, but the difference was not statistically significant.

As in Experiment 1, there were no significant differences in the digestibility of dry matter or protein between pigs or between periods. However, in this experiment there was a significant difference in the B.V. of the protein between periods (i.e. ages of pigs). The average B.V.'s for periods 1, 2, 3, and 4 were 55.2, 52.2, 44.3, and 46.4, respectively, indicating, as has been reported (5 and 29) that as pigs get older and heavier they utilize protein less efficiently when fed a constant level of protein. The average weights of the pigs during periods 1, 2, 3, and 4 were 60, 89, 127, and 149 lb., respectively.

Experiment 3

The data obtained in Experiment 1 indicated considerable reduction in digestibility and feed value due to severe frost damage which had occurred at an early stage of maturity. The question arose as to whether frost damage, per se, or the early stage of development that the crops were in when growth was stopped by frost had altered the digestibility and utilization of the protein.

To study the effect of wheat harvested at an early stage of growth, as compared to wheat frozen at an early stage of growth, a field of Reliance wheat at Lethbridge was harvested at early stages of maturity in an effort to produce light-weight wheat comparable to the frost-damaged 30 lb.- and 44 lb.- per bushel wheat used in Experiment 1. This was approximately 14 and 22 days after flowering. The dry matter contents were 35 and 44

per cent at time of cutting. However, the bushel weights of these samples when thrashed were 41 and 58 lb. Johnson and Whitcomb (19) and Newton and McCalla (25) reported that frosted wheat had a lower weight per bushel than non-frosted wheat cut at the same stage of maturity. This was attributed to the looser packing of the blistered kernels.

Rations were compounded using wheats No. 1 and No. 2 from Experiment 1 and wheats A (early cut non-frozen) and B (medium-early cut and non-frozen) harvested in 1953. The protein contents of all rations were reduced to approximately 11.5 per cent by the addition of starch. This required the addition (per 100 lb. of wheat) of approximately 4 lb. starch to the early-cut wheat; none to the medium-early cut wheat; 43 lb. to the severely-frozen wheat, and 28 lb. to the medium-frozen wheat. Minerals, vitamins, and antibiotics were added as in Experiment 1.

Table 2 shows the chemical composition of the wheats and rations used in Experiment 3. The early-cut wheat did not have as high contents of ether extract and crude fibre or non-protein nitrogen as the frost-damaged wheat. This, probably, is due to translocation of nutrients and respiration changes that continue after immature, non-frozen grain is harvested in contrast to the cessation of these changes when the plants are frozen severely (26).

TABLE 5.—AVERAGE FEED INTAKE, DIGESTIBILITY, ENERGY, AND NITROGEN UTILIZATION OF RATIONS AND WHEAT AS INFLUENCED BY STAGE OF MATURITY AND FROST DAMAGE (EXPERIMENT 3).

	Ration A	Ration B	Ration C	Ration D	Necessary difference
	Early cut	Medium-early cut	Severe frost	Medium frost	
					p = 0.01
Wt./bu. of wheat in ration (lb.)	41.0	58.0	33.0	44.0	—
Av. wt. of pigs (lb.)	63.0	59.0	59.0	60.0	—
Av. daily feed intake (lb.)	3.3	3.2	3.2	3.2	—
Av. daily protein intake (lb.)	0.37	0.36	0.35	0.35	—
Av. daily gain (lb.)	1.0	1.1	1.0	1.0	—
% D.M. of ration digested	82.4	85.4	79.3	81.9	0.1
Digestibility Coefficient of Grain[1]					
Dry matter	82.6	86.2	73.3	79.4	0.2
Organic matter	83.2	86.9	73.6	79.9	0.9
Protein (apparent)	76.5	80.0	69.9	73.0	7.5
Protein (true)[2]	88.1	90.8	81.7	84.7	6.9
Crude fibre	23.0	30.2	17.3	19.3	5.6
Ether extract	53.8	54.8	59.1	62.7	12.2
Nitrogen-free extract	88.9	91.4	81.8	86.4	0.5
Gross energy	80.0	84.7	70.7	76.2	0.7
% Protein retained of feed (apparent)	37.2	33.0	34.7	32.2	9.4
B.V. of protein	62.4	54.8	64.6	59.2	6.0
Net protein utilization	47.7	43.8	45.2	43.2	—
% T.D.N. of grain	74.7	77.5	67.7	72.3	2.0
% Metabolizable energy of grain[3]	77.8	82.7	68.6	73.8	0.8
Digestible energy of grain (therms/100 lb.)	142.6	153.0	136.2	141.6	1.9
Metabolizable energy of grain (therms/100 lb.)	138.8	149.4	132.1	137.3	2.0

[1] Assuming that the D.M. of the starch is 95 per cent digestible and the D.M. of the mineral mix is 50 per cent digestible.
[2] Corrected for M.F.N.
[3] Assuming that the digestible energy of starch is 95 per cent metabolizable.

Four barrow pigs, similar in breeding and type to those in Experiments 1 and 2, were used to evaluate the digestibility and nitrogen utilization of the rations. They averaged 28 lb. at the beginning and 88 lb. at the completion of the experiment. The design of experiment, methods of feeding, collection of feces, and methods of chemical analyses and calculations, were the same as in Experiment 1. Total energy of the urine was determined in this experiment using the method outlined by Forbes and Garrigus (15) so as to determine metabolizable energy of the ration.

Results of this experiment are shown in Table 5. The D.M. and O.M., protein (true), crude fibre, N.F.E., and gross energy of the early-cut wheat were more highly digestible than the same constituents of wheat frozen at approximately the same stage of maturity. This, no doubt, was due to the early-cut wheat filling after cutting and resulting in wheat of lower crude fibre content and a higher starch content. Cutting wheat at an early stage of maturity significantly lowered the digestibility of the dry matter, organic matter, crude fibre, N.F.E., and gross energy but increased the B.V. as compared to wheat cut one week later. The severely frozen wheat (Ration C) used in this experiment was more highly digestible than the wheat used in Ration No. 1 in Experiment 1. This is difficult to explain as both wheats were from one lot of wheat before cleaning out the chaff, weed seeds, etc. The fact that the cleaned sample of wheat used in Experiment 1 was of lower bushel weight and higher fibre and protein content than the wheat used in Experiment 3 might indicate that less light wheat was removed with the chaff, etc. in cleaning the sample for Experiment 1, than was the case for Experiment 3.

As found in Experiment 2 the B.V. of the protein decreased significantly as the pigs became older and heavier. The average B.V.'s for periods 1, 2, 3, and 4 were 65.8, 60.4, 58.4, and 56.4, respectively. The average weights of the pigs during these periods were 30, 56, 70, and 84 lb., respectively. With the exception of the period differences in the B.V. of the protein there were no significant differences between periods or pigs in the digestibility of the various nutrients studied.

It may be concluded that the effect of severe frost damage in lowering the digestibility of wheat by swine is not the same as the effect of harvesting at the same stage of maturity.

WEIGHT PER BUSHEL AND FEEDING VALUE

The correlation coefficient between weight per bushel of wheat and T.D.N. was 0.81 ($P \leqq 0.01$) and between weight per bushel and digestible energy (therms per cwt.) was 0.89 in the three experiments. The corresponding regression coefficients were 0.4 and 1.0, respectively. This would indicate that the digestible energy value of wheat, irrespective of frost damage, is closely associated with bushel weight. Crampton [(12) and personal communications], Wright (34), and others have suggested that weight per bushel is a good index of the feed value of cereal grains.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of J. Courant, who fed and cared for the animals used in these experiments. They also wish to express appreciation to G. D. Matthews and H. E. Wilson, Superintendents at the Experimental Stations at Scott, Saskatchewan, and Melfort, Saskatchewan, respectively, who supplied part of the grain used in these experiments.

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THE NUTRITIONAL VALUE OF FIRE-DAMAGED WHEAT FOR SWINE[1]

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[Received for publication June 9, 1954]

ABSTRACT

The nutritional value of fire-damaged wheat for swine was studied by use of digestion, and nitrogen and energy utilization experiments. The utilization of the protein of severely fire-damaged wheat was not reduced significantly when compared to slightly fire-damaged wheat but was less than that of normal wheat. The digestible energy content of severely fire-damaged wheat was significantly less than that of slightly fire-damaged and normal wheat. Fire-damaged wheat was less palatable than normal wheat.

Each year fire destroys a number of grain storage elevators. This results in many thousands of bushels of grain being rendered unfit for milling and processing purposes. If this grain is to be salvaged, some other use must be found for it. Its use as a livestock feed is one possibility. However, if it is to be used efficiently as a feed, its comparative value with non-damaged grains should be known. Since there have been no experiments reported in the scientific literature on the value of fire-damaged grain for livestock, a study was undertaken to gather some information on this subject.

PROCEDURE

A quantity of wheat from a grain storage elevator that burnt in November, 1953, at Picture Butte, Alberta, was obtained for this study. This grain first was put through a fanning mill to remove nails, glass, pieces of charred wood, fine charcoal dust, and weed seeds. These materials amounted to approximately 14 per cent of the total weight. The remainder was put through the fanning mill again and by the control of wind and the use of various sieves the more severely fire-damaged grain (*Sample A*) was separated from the less severely fire-damaged grain (*Sample B*). *Sample A* contained approximately 60 per cent charred, 20 per cent partly charred, and 20 per cent smoke-damaged grain. It weighed 40 pounds per bushel. *Sample B* contained approximately 5 per cent charred, 10 per cent partly charred, 60 per cent smoke-damaged, and 25 per cent non-damaged grain. This grain weighed 54 pounds per bushel.

Rations A and B were compounded from these two lots of wheat by mixing 5 lb. of dried skimmilk, 95 lb. of grain, and half a pound of an aureomycin preparation (Aurofac 2A).[3] Digestion and nitrogen balance experiments were conducted on these rations with four Yorkshire barrows weighing approximately 90 lb. in body weight. Two 2 × 2 Latin square designs were used in allotting the pigs to their rations. Methods of feeding, collection of feces and urine, chemical analysis, and calculations were the same as previously described by Whiting and Bezeau (3).

[1] Contribution from the Division of Animal Husbandry, Experimental Farms Service, Canada Department of Agriculture, Ottawa.

[2] Animal Nutritionist and Chemist (Animal Nutrition), respectively.

[3] The Aurofac 2A used in this experiment was generously supplied by Lederle Laboratories, Pearl River, N.Y.

TABLE 1.—CHEMICAL ANALYSIS, DIGESTIBILITY, AND NITROGEN UTILIZATION OF FIRE-DAMAGED, FROST-DAMAGED, AND NORMAL WHEAT

(Calculated to 10 per cent moisture basis)

		Wheat A fire-damaged (severe)	Wheat B fire-damaged (slight)	Frost[1] damaged	Normal[1]	Necessary difference (P =0.01)
Wt. per bushel	(lb.)	40	54	58	66	—
Av. wt. pigs on experiment	(lb.)	98	99	107	105	—
Av. daily feed consumption	(lb.)	3.7	3.6	5.7	5.1	—
Av. daily gain on experiment	(lb.)	0.8	0.8	1.7	1.6	—
Chemical Composition						
Moisture	(%)	10.0	10.0	10.0	10.0	—
Protein (N × 6.25)	(%)	11.8	10.5	15.2	15.7	—
Ether extract	(%)	1.9	1.9	1.8	1.8	—
Crude fibre	(%)	19.4	3.4	3.0	2.4	—
Ash	(%)	2.5	1.9	1.6	1.2	—
Nitrogen-free extract	(%)	54.4	72.3	68.4	69.0	—
Gross energy	(Cal./gm.)	4.6	4.1	4.0	4.0	—
Digestibility[2]						
Dry matter	(%)	70	86	85	89	2
Organic matter	(%)	71	87	85	89	2
Protein—apparent	(%)	49	65	83	89	3
Protein—true[3]	(%)	63	76	91	96	3
Ether extract	(%)	62	60	42	51	7
Crude fibre	(%)	13	17	18	22	8
Nitrogen-free extract	(%)	97	95	94	96	2
Gross energy	(%)	63	84	85	88	2
Protein Utilization[2]						
Per cent of protein retained of fed		16	17	29	30	6
Biological value (B.V.) of protein		59	49	45	43	8
Net protein utilization (B.V. × digestibility)		29	32	37	38	—
Energy Utilization						
Digest. energy (therms/100 lb.)		134	154	155	160	3
Metabolizable energy (therms/100 lb.)		130	149	—	—	—
Total digestible nutrients (%)		63	78	77	80	3

[1] The data for the frost-damaged and normal wheat were obtained in a previous experiment (3).

[2] Assuming that the digestibility of the organic matter and protein of dried skimmilk was 98 per cent and that the B.V. of the protein was 100 per cent.

[3] Corrected for metabolic fecal nitrogen (3).

The results from this experiment were compared to those obtained with normal (No. 2 Northern grade) and frost-damaged (feed grade) wheat used in a previous experiment (3). The pigs used in both experiments were of similar breeding and weight, and the rations were of similar composition.

RESULTS AND DISCUSSION

Both rations containing fire-damaged grain proved to be very unpalatable. It was necessary to keep the pigs on the preliminary period for approximately two weeks before they became accustomed to the ration. Livestock feeders in the Lethbridge area have reported that it takes approximately 10 days to accustom stock to eating fire- and smoke-damaged grain.

The results of this experiment, together with data from a previous experiment, are shown in Table 1. On chemical analysis, the severely fire-damaged wheat (A) showed an apparent crude fibre content of 19.4 per cent, whereas the slightly fire-damaged wheat (B) showed a crude fibre content of 3.4 per cent. Further analyses showed that the high apparent crude fibre content of wheat A was due to the charred particles (charcoal) which were not dissolved by the acid and base used in crude fibre determinations. Also, the total energy of this wheat was considerably higher than that of the slightly fire-damaged wheat because of the higher carbon content of the charred grain.

The digestibility of the dry matter, organic matter, protein (apparent and true), and total energy of wheat A was significantly less ($P < 0.01$) than that of wheat B. The digestibility of the slightly fire-damaged wheat, with the exception of protein, was very similar to that of frost-damaged and normal wheat. Although the digestibility of the protein of wheat A was significantly less than that of wheat B, the digested protein was utilized more efficiently (i.e. it had a higher Biological Value, B.V.). This resulted in no significant difference in the net utilization of the protein (B.V. $\times$ digestibility) from the two wheats. The reason for the higher B.V. of the protein from the severely fire-damaged wheat is not known. It may have been due to a greater economy of use of the digested protein since less was available to the body.

The energy value of the slightly fire-damaged wheat, as measured by digestible energy (therms) or T.D.N., was equal to frost-damaged wheat and only slightly less than normal wheat. The value of the protein of fire-damaged wheat was less than that of frost-damaged and normal wheat.

The digestibility of the crude fibre of the severely fire-damaged wheat was 13 per cent. Since this apparent crude fibre was largely charcoal (carbon) it is evident that the pig is not able to utilize charred grain efficiently. Totusek and Beeson (1) and Totusek *et al.* (2) have reviewed the literature on the value of charcoal for swine and have presented data which show that little, if any, advantage is to be gained by adding wood charcoal to balanced rations for growing and fattening swine.

The feed value of burnt grain will depend therefore, on the amount of fire damage to the grain (i.e. the per cent charred grain) and the amount of foreign material (wood, glass, nails, etc.) present. This material should be removed before feeding. The apparent crude fibre content could be used as a simple chemical method to determine the amount of charred grain present.

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IMPROVEMENT IN LOW TEMPERATURE RESISTANCE OF SUGAR BEET AND GARDEN BEET SEEDLINGS TREATED WITH SODIUM TCA AND DALAPON

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[Received for publication July 14, 1954]

ABSTRACT

Sugar-beet and garden-beet seedlings were grown in darkness and high humidity for 6 days at approximately 21.5° C. in Petri dishes containing vermiculite moistened with a standard volume of water or with 4 to 8 p.p.m. active concentration of TCA (sodium salt of tricholoroacetic acid) or of Dalapon (sodium salt of 2,2-dichloropropionic acid). Shoots were then cut off and attached basally to horizontal bands of Scotch tape on a wire frame and rotated slowly during controlled exposures to −10° C. for periods of 5 to 10 minutes. Such treatments revealed highly significant improvement in cold resistance of chemically treated seedlings as judged by numbers of seedlings surviving their exposures in the freezer.

Effects of Dalapon (sodium formulation of 2,2-dichloropropionic acid) in increasing the low temperature resistance of etiolated sugar beet seedlings have been noted in a previous paper (2). The present article reports similar effects induced by a structurally similar chemical TCA (sodium formulation of trichloroacetic acid). The difference in structure is a third chlorine atom on number two carbon of TCA (Cl_3CCOO Na) in place of a methyl group present in Dalapon (CH_3CCl_2COO Na).

Seeds of sugar beet variety Kuhn and of Detroit Dark Red garden beets were planted and grown in vermiculite moistened with tap water or chemical solutions as described earlier (2). On the sixth or seventh day after planting, the seedlings were removed from the dark chamber and prepared for exposure to cold treatments. Twenty-five severed shoots from each treatment in each replicate were attached side by side, basally, on bands of 0.5 inch Scotch tape, suspended with adhesive side up, between ends of a support. This was made by bending upwards for 1 inch at right angles the ends of a rectangular frame of stiff wire. The frames of seedlings were then slowly rotated horizontally on a circular shelf near the bottom of a freezer chest. The vertical axle of the shelf was driven by a small externally mounted electric motor.

Upon removal of frames after specified low temperature treatments, frozen seedlings thawed in a few moments and their portion protruding beyond the edge of the tape collapsed. Survivors were counted and recorded in percentage of sample used. Permanence of damage to non-survivors was verified by a number of tests in which the seedlings, after exposure to the appropriate low-temperature treatments, were either left at room temperature for the remainder of the day or placed in water at room temperature for several days. Seedlings originally recorded as survivors retained a normal appearance while the frozen plants shrivelled to darkened threads of tissue. In the tests with garden beets there was readily visible

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diffusion of red pigment into the water surrounding frozen seedlings. Representative results are shown in the following tables:

TABLE 1.—SUMMARY OF COMPARABLE EXPERIMENTS SHOWING EFFECTS OF TCA ON LOW TEMPERATURE RESISTANCE OF SUGAR BEET SEEDLINGS

	Percentage of survival[1]			
	Check	Acid equivalent, TCA		
	0 p.p.m. (4 experiments)	4 p.p.m. (4 experiments)	6 p.p.m. (2 experiments)	8 p.p.m. (2 experiments)
Exposure time[2]—				
(*a*) 6 min.	44	60	62	64
(*b*) 8 min.	22	45	50	50
(*c*) 10 min.	11	34	40	42

[1] Mean per cent of survival over all experiments, each with four replicates and a 25-seedling sample for each treatment per replicate. In each experiment the TCA treated plants were statistically significantly more resistant to cold than the checks.

[2] (*a*) Five min. at −10° C. and approx. 2 min. observation at room temperature.
(*b*) Second exposure of same material for 8 min. at −10° C.
(*c*) Third exposure for 10 min. at −10° C.

TABLE 2.—COMPARISON OF EFFECTS OF TCA AND DALAPON ON LOW TEMPERATURE RESISTANCE OF SUGAR BEET AND GARDEN BEET SEEDLINGS

(Mean per cent of survival after exposures at −10° C. Four replications, 25 seedlings each, 6 days after planting)

Time[1]	Check	Acid equivalent			
		TCA		Dalapon	
	0 p.p.m.	4 p.p.m.	8 p.p.m.	4 p.p.m.	8 p.p.m.
Sugar Beets—					
(*a*) 6 min.	46	65	70	69	80
(*b*) 8 min.	17	54	58	59	69
(*c*) 10 min.	6	42	49	40	58
Garden Beets—					
(*a*) 6 min.	53	73	85	91	—
(*b*) 8 min.	32	60	81	80	—
(*c*) 10 min.	13	54	78	76	—

[1] (*a*) Five min. at −10° C. and approx. 2 min. observation at room temperature.
(*b*) Second exposure of same material for 8 min. at −10° C.
(*c*) Third exposure for 10 min. at −10° C.

DISCUSSION

The reasons for the effects produced by TCA and Dalapon have not yet been discovered. Preliminary experiments on root and shoot growth of treated and untreated sugar beet seedlings, their moisture content, and rate of wilting in dry atmosphere have given no clear indication of differences attributable to these factors.

Similar freezing experiments with treated and untreated seedlings of Altaswede red clover, Ferx alfalfa, Pencil Pod Black Wax beans and Hollow

Crown parsnips have given no conclusive results. The influence of various treatments on chemical constituents of the plants, and the effects of different pre-hardening periods before freezing exposures of different varieties and species of plants are receiving attention in further efforts to understand the problem.

Slow and erratic germination of parsnip seeds has hindered progress of laboratory studies with this species. In view of the improved frost resistance observed with sprayed field grown parsnips during 1952 (1) it is of particular interest to attempt to obtain a similar response in the laboratory.

ACKNOWLEDGMENTS

Grateful appreciation is expressed to the joint sponsors of this research project, viz., the National Research Council of Canada, the Federal Department of Agriculture and the University of Alberta. Dow Chemical Co. has donated supplies of chemicals for experimental purposes.

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AN IMPROVED EXPERIMENTAL PLOT SEEDER[1]

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[Received for publication December 30, 1953]

It has been well established (1, 2, 3, 5, 6) that, under normal conditions of soil moisture, deep seeding is more favourable to smut infection of cereals than is shallow seeding. Also, seeding sufficiently deep to get the seed into moist soil is conducive to uniform germination and the germinating seed is not likely to be blown out by wind storms. The widely used V-belt plot seeder (4) is not adapted for deep seeding except in light sandy loams. On heavy soil like Red River silty clay it is impossible to seed deeper than just below the loose dry layer of soil because damp clay sticks to the blunt shoe furrow opener.

To overcome these difficulties, one of the V-belt plot seeders was modified in 1952 by substituting a double disk for the ordinary shoe furrow opener. This change necessitated raising the belt-driving mechanism considerably higher, thus making the seeder top-heavy. Although it was not difficult to push the seeder forward even at 4-inch depth of seeding, it was rather hard to handle it for any length of time, owing to its increased height and weight.

Early in 1953 a completely new plot seeder was built (Figures 1, 2, 3[3]). The disk furrow opener was reduced to 12 inches in diameter and the heavy cast iron frame that comes with such disks was replaced by a light and simple frame (Figure 2). Depth adjustment is controlled by a coarse-threaded screw which makes it possible to seed at any depth from 0 to 5 inches. The frame of the seeder is made of steel tubing which is relatively light in weight but is sturdy enough for the purpose. The whole seeder is only 9 lb. heavier than an ordinary V-belt plot seeder but, being shorter and more compact, it is easier to operate.

The seed distributor consists of an aluminum cone (Figure 1, B) set in a circular metal pan (Figure 1, E) with a plastic wind guard (Figure 1, C). On top of the conical head is a small metal container machined to fit snugly over the tip of the cone (Figure 1, A). This container is made to hold up to 18 grams of cereal seed (55 cc.) and it slides up and down on a straight rod secured through the tip of the conical head. The conical head is rotated by a set of four gears, each of which is of a size to rotate the head exactly one complete turn for a desired length of plot. The present machine is geared to seed 6-, 8-, 10- and 18-ft. plots. If a still different length of plot is desired, a different gear may be fitted for that purpose. In fact, with a slight modification of the gear assembly (Figure 3, F), up to eight different lengths of plot can be seeded. The gears run in oil and this assures smooth operation and prevents wear.

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FIGURE 1. Side view of the new seeder, showing details of the seed distributor.
FIGURE 2. Front view, showing the frame, disk furrow opener and the gear assembly box.
FIGURE 3. Showing the method of placing seed into the distributor.

The following advantages of the new seed distributor are noteworthy:

(1) It provides a low-set, compact and easily operated seeder.

(2) The operator simply dumps a package of seed into the container (A), lifts it and the seed falls evenly over the cone into a quarter-inch wide rim whence it is delivered through the spout (D) into the furrow. Thus, the necessity of walking from behind the handles of the seeder and distributing seed evenly over a belt is eliminated and, therefore, considerable time and effort are saved.

(3) Neither wind nor vibration can disturb the seed, hence a seeder with this kind of distributor can be adapted to power-driving.

(4) When seeding differently treated seed lots it can readily be cleaned by lifting the wind-guard and wiping the smooth cone with a damp rag while the seed container can be dipped in alcohol or any other cleaning solution.

(5) The new distributor may be adapted to a garden seeder, since the rate of seeding with it is not dependent on the size of seed.

A thorough trial of the new seeder in the spring of 1953 revealed that it is easier to handle, even at 4-inch depth of seeding, than the V-belt seeder at 1-inch depth. It can be used satisfactorily on soil too moist for seeding with the V-belt seeder. Moreover, on 6-foot long plots one person can seed approximately twice as fast as with the V-belt seeder. By the use of lighter metal alloys the seeder can be further reduced in weight and made still easier to handle.

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PHOSPHORUS CONTENT OF POTATO PLANTS IN RELATION TO YIELD AND TO PHOSPHORUS CONCENTRATIONS IN NUTRIENT SOLUTIONS[1]

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[Received for publication June 5, 1954]

ABSTRACT

The relationship between the phosphorus content of the potato plant and yield was studied by means of sand pot culture conducted in the greenhouse.

In the petioles there was a lack of relationship between either soluble or total phosphorus and the levels of phosphorus in the nutrient solutions from 5 to 20 p.p.m. even though there was a significant increase in yield with each increase of phosphorus supply within this range. There was a marked progressive increase of phosphorus content when the nutrient solutions contained 30 to 75 p.p.m. but the yield increase of 12 per cent was not significant. In the leaf blades or whole plant top there was a slight progressive increase of soluble phosphorus when the nutrient solutions contained less than 30 p.p.m. but a marked progressive increase beyond this level.

A continuous relationship was obtained between the total phosphorus content in the leaf blades or whole plant top and the phosphorus supply, and the total phosphorus content provided a wider range of values at the lower levels of phosphorus supply than did the soluble phosphorus determinations.

The determination of total phosphorus in the leaf blades provided the best relationship index between yield and the phosphorus content of the plant. The total phosphorus content of leaf blades of adequately nourished potato plants should probably be not less than 0.35 per cent.

INTRODUCTION

The relationship between potato yields and the phosphorus content in the plant has been reported by several workers. Results in the different studies have varied considerably and the relationship has not been precisely determined in any one study.

Carolus (1) extracted the soluble phosphorus with 2 per cent acetic acid from the lower portion of the main stem and reported a minimum requirement of 150 p.p.m. (fresh weight basis) at the beginning and 60 p.p.m. at the close of the season. Lorenz (4) extracted the petiole (rachis) tissue with the same extracting solution and noted that during the most rapid period of growth, on plots which did not receive any application of phosphorus, the soluble phosphorus was less than 70 p.p.m. and that this level may have been associated with a slight reduction in yield. Nicholas (5) reported that chemical values of soluble phosphorus did not agree with visual data and suggested that the tissue method for determining phosphate in "acid" plants must be re-examined to establish whether the values accord with the total phosphorus content. Using 2 per cent acetic acid extracts of the plant petioles, Hill and Cannon (2) found no apparent reduction in yield with phosphorus levels at 42 or 46 p.p.m. (fresh weight basis) in plants grown on muck soil, sampled six to seven weeks after planting. Terman *et al.*

[1] Joint contribution from the Experimental Farms Service and Science Service. Contribution No. 825, Horticulture Division; and Contribution No. 256, Chemistry Division.
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(6) concluded that only in the samples taken at the early bud stage was the content of soluble phosphorus in the petioles consistently related to the amount of phosphorus applied in the fertilizer or to the yield of tubers. In further studies conducted on non-organic soil, Hill (3) noted an increase in yield when the soluble phosphorus in the petioles, sampled six weeks after planting, increased from 28 to 49 p.p.m., and a slight but not significant increase in yield up to a level of 69 p.p.m.

Thomas *et al.* (7) reported an optimum value of total phosphorus of 0.30 per cent (dry weight basis) in the fourth leaf from the base of the primary stem when sampled approximately seven weeks after planting.

The objectives of this study were to determine the particular plant part in which the phosphorus content was most closely related to phosphorus treatment and yield of tubers, and to determine critical levels of various phosphorus fractions.

MATERIALS AND METHODS

Sprouted eyes of Green Mountain potatoes were planted in the greenhouse in washed river sand in glazed 3-gallon crocks, February 23, 1953. Each treatment comprised six crocks. Two of the three eyepieces in each crock provided plant material for analysis and the third was grown to maturity to provide yield data. Nutrient solutions were applied on the sand surface at intervals according to moisture requirements. For the first two weeks solutions were employed at only one-half concentration; thereafter they were used as described in the text. The basic nutrient solution contained the following element concentrations in parts per million: N 336, K 257, Mg 19.5, Ca 16, S 25.8, Mn 0.19, B 1.0, Fe 8.3. The reagent grade chemicals used as the source were: $MgSO_4 \cdot 7H_2O$, KH_2PO_4, KNO_3, $Ca(NO_3)_2 \cdot 4H_2O$, NH_4NO_3, $MnSO_4 \cdot 2H_2O$, H_3BO_3, $FeCl_3 \cdot 6H_2O$.

The nine treatments, numbered 1 to 9, contained 0, 5, 10, 15, 20, 30, 40, 50 and 75 p.p.m., respectively of phosphorus.

Samples for analysis were taken on March 23 and April 21. At the first date of sampling soluble phosphorus in the petioles, main stems and entire plant, excluding roots, was determined on extracts of fresh tissue prepared in a Waring Blendor with (*a*) 2 per cent acetic acid and (*b*) cold trichloroacetic acid. Darco G60 decolourizing carbon was employed to clarify the extracts. The methods of analysing the extracts were similar to those described by Ward and Johnson (8). Total phosphorus in the whole plant, excluding roots, was determined on hydrochloric acid solutions of dry-ashed material. At the second date of sampling soluble phosphorus was determined on leaf blades, petioles and whole plant, excluding roots, again by extraction with (*a*) and (*b*) as at the first sampling date. The trichloroacetic acid extracts were also hydrolyzed and determinations made of organic phosphorus. Determinations were also made of total phosphorus in dry ash of the leaf blades, petioles and whole plant, excluding roots.

EXPERIMENTAL RESULTS

Growth Observations

Plants receiving 75, 50 and 40 p.p.m. of phosphorus in the nutrient solutions were healthy and vigorous; all showed initial flower buds one

TABLE 1.—THE EFFECT OF PHOSPHORUS UPON PLANT GROWTH AND TUBER YIELD

P in nutrient solutions	Height of plant	Green weight of tops	Total weight of tubers	Weight of marketable tubers	Yield increase between treatments
p.p.m.	in.	gm.	gm.	gm.	%
0	5.2	20	308	0*	—
5	5.9	206	964	729	—
10	5.2	462	1948	1857	155
15	6.1	925	3143	3054	64
20	6.5	1306	3843	3633	19
30	7.0	1482	4114	3800	5
40	8.2	1642	3997	3712	−2.3
50	8.6	1902	4299	3930	3
75	9.4	1582	4365	4092	4

* Significant difference at P 0.05 = 654.

month after planting. Plants receiving 30 p.p.m. were only very slightly reduced in vigour. There was a distinct drop in vigour and height of plants with a solution concentration of 20 p.p.m., and a progressive and marked decrease in vigour at lower concentrations. Plants receiving 0-15 p.p.m. were characterized by a short, upright, spindly type of growth with the foliage being a dull, dark green. In another two weeks the foliage in the first two treatments had become a dirty, yellow-green and the margins of the leaves curled towards the mid-ribs. At the leaf tips small water-soaked greyish areas occurred which later turned brown, producing a tip-burn effect. Plants in the zero phosphorus treatment finally died (Figure 1). Plant height, green weight of the top, weight of tubers and weight of marketable tubers in each treatment are recorded in Table 1.

Large increases in vigour and yield were obtained with each 5 p.p.m. increase of phosphorus in the nutrient solution up to 20 p.p.m. Increasing the concentrations from 20 to 75 p.p.m. did not result in a further significant increase in yield. The latter point is pertinent to the following discussion of the relationship between phosphorus content of the plant and yield.

Chemical Composition

The soluble phosphorus in the petioles, stems and whole plants and the total phosphorus in the whole plants, in samples collected on March 23 are recorded in Table 2. The levels of soluble phosphorus obtained by both the acetic acid and trichloroacetic acid extractions are very similar so that the discussion will apply to both.

FIGURE 1. Leaf symptoms of phosphorus deficiency. Water-soaked greyish areas turning brown later to produce a tip-burn effect.

TABLE 2.—PHOSPHORUS CONTENT OF PLANTS SAMPLED MARCH 23, AS RELATED TO TREATMENT AND YIELD

P in nutrient solution, p.p.m.	Soluble P (p.p.m. fresh weight)						Total P, per cent dry weight	Marketable yield, gm.
	Petioles		Stem		Whole plant		Whole plant	
	Acetic acid extract	TCA extract	Acetic acid extract	TCA extract	Acetic acid extract	TCA extract		
0	22	38	18	39	51	39	0.245	0
5	25	25	17	—	43	32	0.232	729
10	22	22	23	35	54	45	0.274	1857
15	30	32	19	33	52	50	0.342	3054
20	33	38	33	32	54	37	0.428	3633
30	91	102	48	52	100	98	0.483	3800
40	152	161	63	108	110	129	0.555	3712
50	175	173	79	81	165	150	0.599	3930
75	158	278	128	125	268	275	0.714	4092

TABLE 3.—PHOSPHORUS CONTENT OF PLANTS, SAMPLED APRIL 21, AS RELATED TO TREATMENT AND YIELD

P in solutions, p.p.m.	Soluble P (p.p.m. fresh weight)							Total P, per cent dry weight			Marketable yield, gm.
	Leaf blades			Petioles			Whole plant	Leaf blades	Petioles	Whole plant	
	Acetic acid	TCA inorganic	TCA inorganic and organic	Acetic acid	TCA inorganic	TCA inorganic and organic	Acetic acid				
0	50	45	58	38	12	22	23	0.133	0.107	0.110	0
5	38	27	42	25	10	19	20	0.127	0.084	0.130	729
10	43	36	62	13	10	19	29	0.181	0.108	0.180	1857
15	48	46	83	25	12	19	33	0.218	0.108	0.201	3054
20	75	53	80	15	10	19	39	0.239	0.110	0.250	3633
30	113	123	169	38	37	50	52	0.357	0.191	0.342	3800
40	125	167	236	85	78	98	115	0.411	0.261	0.413	3712
50	223	197	233	150	151	155	191	0.492	0.352	0.460	3930
75	500	392	465	288	290	273	325	0.653	0.652	0.590	4092

The levels of soluble phosphorus in the petioles and in the entire plant were not significantly different in character but the range of values found in the stem was much narrower, which shows that this tissue is less suitable as an indicator. The significant feature in both petiole and entire plant was the lack of relationship between soluble phosphorus content of the tissue and levels of phosphorus in the nutrient solutions from 5 to 20 p.p.m. even though there was a marked increase in yield with each increase of phosphorus supply within this range. There was a marked progressive increase of soluble phosphorus content when the nutrient solutions contained 30 to 75 p.p.m. of phosphorus, but as previously noted the yield increase in this range was only 12 per cent and is not statistically significant. The lack of continuous relationship between soluble phosphorus and yield is a serious defect in establishing critical levels. In comparison there was a measurable increase of total phosphorus in the entire plant with each increase of phosphorus in the nutrient solutions and with yield increases. It appears from these data that the levels of total phosphorus in the plant present a more constant and reliable yield relationship index than those of soluble phosphorus.

The phosphorus content of different portions of the plants sampled on April 21 will be found in Table 3. The results were similar to those obtained at the first date of sampling in respect to the soluble phosphorus content of the petioles. There was a progressive increase of soluble phosphorus in the leaf blades and whole plant throughout the entire range of increasing phosphorus in the solutions. There appears to be a sufficient relationship between yield and soluble phosphorus content of the leaf blades or whole plant to warrant the assumption that critical levels might be established. The sum of the organic and hydrolysable phosphorus in the trichloroacetic acid extract showed a somewhat wider range of values than the other determinations of soluble phosphorus, thus offering more scope for establishing a relationship at the lower concentrations.

While the soluble inorganic phosphorus content or the total soluble phosphorus content of the leaf blades may offer a suitable relationship index with yield, data from the first date of sampling indicated that the determination of total phosphorus provided a more reliable index at the lower levels. Determinations of total phosphorus in the leaf blades, petioles and whole plant are presented in Table 3. It is apparent that there was no relationship between the total phosphorus content in the petioles and the levels of phosphorus in the nutrient solutions from 5 to 20 p.p.m. although there was a straight line relationship above this point. This type of discontinuous relationship is similar to that obtained with the soluble phosphorus content of the petioles and indicates that the petiole or rachis is not a suitable portion of the plant to employ. In contrast there is a progressive increase or continuous relationship of total phosphorus in either the leaf blades or whole plant with each increment of phosphorus in the nutrient solutions.

A comparison between the relationship obtained with the soluble phosphorus and with the total phosphorus in the leaf blades shows that the latter provides a wider range of values at the lower levels of phosphorus

supply and that there is no sharp break in the relationship index over the whole range. This is not true for soluble phosphorus. On the basis of the data presented, the critical level of total phosphorus in the leaf blades should be in the neighbourhood of 0.35 per cent.

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NOTE ON THE EFFECT OF ULTRASONIC VIBRATION ON DEVELOPMENT OF BARLEY

In experimental studies on the mutagenic properties of ultrasonic vibrations, it was noted that treated barley plants tended to mature earlier than untreated plants. The present experiment was undertaken to test more critically a possible causal relation between such treatments and early maturity.

Seeds of barley varieties, Olli (early) and Montcalm (medium), were sprouted in a germinator for 48 hours and then treated with ultrasonic vibrations for periods of 0, 6, 12 or 18 minutes. The ultrasonic generator produced a fixed frequency of 800,000 cycles/sec. at 5 W/cm.^{2} intensity. Treatment was through deaerated water at a distance of 9 cm. Treated seedlings were planted immediately in the greenhouse as a four-replicate, randomized blocks design. Each experimental unit (row) consisted of 22 plants.

Data on heading time and plant height are given for both varieties in Table 1.

The most striking result is the effect of the 6-minute treatment on days to heading. Compared with untreated material, this treatment gave in every replicate appreciably earlier heading in both varieties. In only one case (Montcalm II, 7.9 as compared to 8.0) did this treatment fail to produce earlier average heading than the other treatments. The 12- and 18-minute treatments proved excessive in some instances in the case of

TABLE 1.—EFFECT OF ULTRASONIC TREATMENT ON HEADING TIME AND HEIGHT IN BARLEY

Replication	Treatment, min.	Av. heading, days*		Av. height, cm.	
		Olli	Montcalm	Olli	Montcalm
I	0	19.3	10.2	32.1	33.5
	6	7.3	6.2	34.1	31.5
	12	8.4	7.8	32.8	27.1
	18	8.8	—**	31.9	—**
II	0	9.8	10.4	34.0	33.8
	6	6.9	8.0	34.7	30.7
	12	7.0	7.9	33.5	27.6
	18	11.2	—**	32.5	—**
III	0	14.5	14.6	33.3	37.7
	6	5.3	7.9	33.4	31.6
	12	13.0	9.0	28.7	30.8
	18	5.9	8.7	33.0	26.6
IV	0	9.3	9.9	34.7	32.7
	6	7.8	7.1	33.1	29.7
	12	10.6	9.0	26.3	28.3
	18	8.5	9.5	29.8	27.6

* Average number of days to heading, after occurrence of first heading in the replicate.
** Missing data due to mortality attributable to overheating during treatment.

Olli, resulting in delayed heading, but consistently produced earlier heading than the control in Montcalm. Analysis of variance, using the individual plant as the experimental unit, showed a highly significant effect of treatments on average days to heading for each variety.

Data on plant height are less striking. In Olli, shorter plants developed after certain of the longer treatments (II, 18; III, 12; IV, 12, 18). In Montcalm, with no damage effect, treatments consistently reduced the average height.

Vibration treatment speeded the heading of two barley varieties, Montcalm (medium) and Olli (early). This suggests that the plant breeder's earliest varieties, for which further genetic improvement may be difficult to attain, might be profitably treated with vibrations. This would apply most practically to the seed of intensively cultivated crops, or crops in areas where the length of the frost-free season is a limiting factor.

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July 12, 1954.